The Chromiferous ultrabasic rocks of the Silam-Beeston range, North Borneo

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THE CHROMIFEROUS ULTRABASIC ROCKS

of the

SILAM-BEESTON RANGE, NORTH BORNEO.

by

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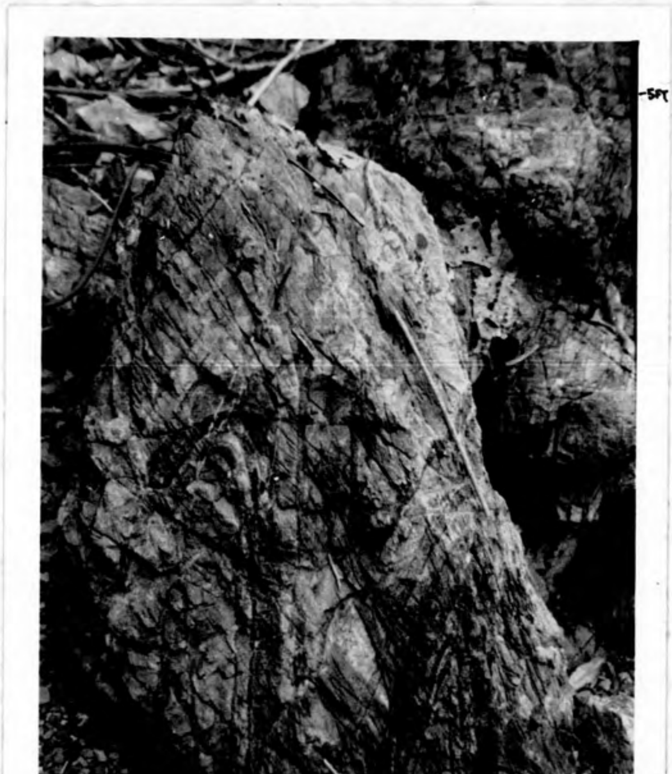

Frontpiece, Subparallel layers of dense ore, folded symmetrically, and showing thickening of chrome ore at crests, Kalung-Kalung Is., Darvel Bay. N.B. (Boulder 5 feet)

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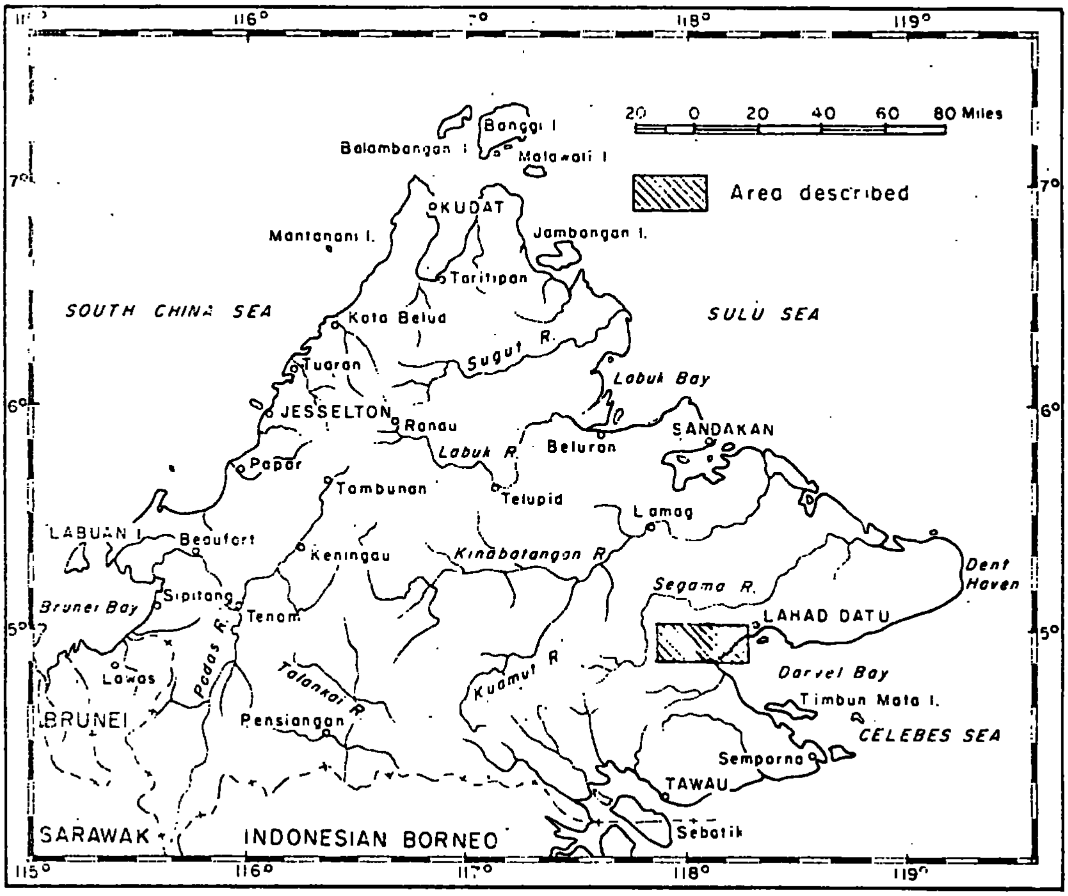


LOCATION OF THE SILAM-BEESTON RANGE.

CHAPTER I

INTRODUCTION

Location and Surface Features.

The igneous intrusive rocks of the Silam-Beeston range crop out in a belt 20 miles long and 1-4 miles wide, between latitudes North 4.55 minutes and 5 degrees, in the Tawau residency, North Borneo. The area is roughly lenticular in shape and the major part follows the north-western coastline of Darvel Bay. Approximately 80 square miles was mapped by Borneo Mining Limited during 1962, on a reconnaissance mapping scale of 1:25.000.

The Saddle Islands form an important group of nine islands in the Darvel Bay and are included for description in the area. They are composed of ultrabasic rocks and extend southeast into the bay from near Silam village. All the islands are small and range in height from between 30-500 feet.

The greater part of the area is uninhabited. The indigenous population is scattered along the coastline of Darvel Bay and consist mainly of the sea faring Idahans. The largest settlement is situated at the western end of Silam Harbour, close to the Kennedy Bay Timber Camp. Small Idahan settlements are situated at Silam Village, below Mount Silam, and in the River Diwata estuary. Timorese, Chinese, and Philippinoes are mixed with Idahans in the timber camps at Kennedy Bay, Silam Harbour and at the Nam Hing Company site in the River Diwata.

Lowland and hill dipterocarp rain forest covers over 80% of the area. Trees rise to 150 feet, occasionally to 200 feet, forming a canopy over the smaller trees and bushes that grow between them. The lower ground is being worked by the two timber companies. The commonest tree species are the white seraya (urat mata); red seraya (Parashorea spp.); kapor (Dryobalanops spp.); and selangan batu (Shorea spp.). Non-dipterocarps include the hard wood belian (Eusideroxylon zwageri).

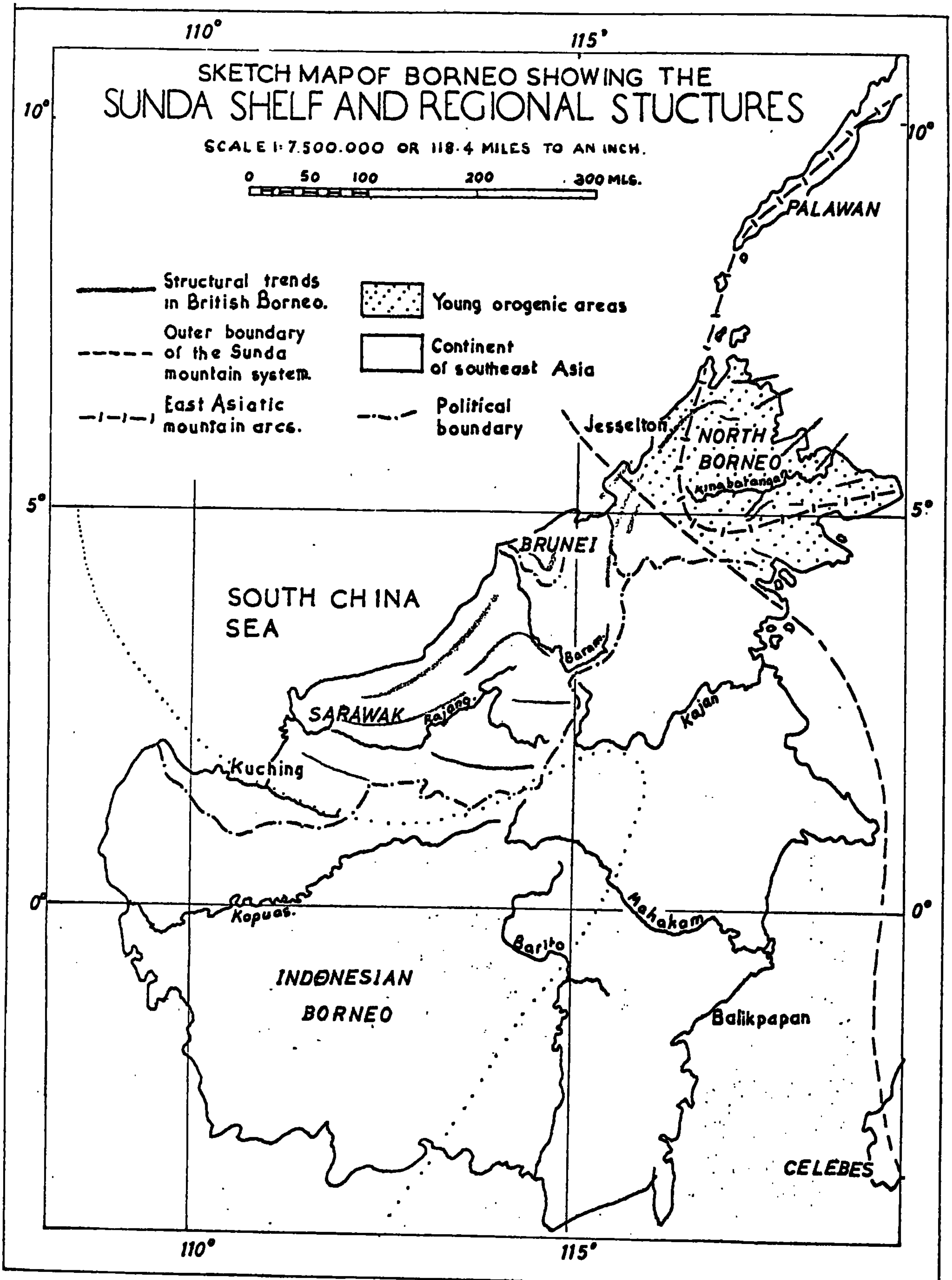
On the high ridge of the Silam-Beeston range, the normal type forest grades into a stunted moss covered type of forest. The trees are small, and low branching, and festooned in moss and creepers, and pitcher plants. Thick moss also covers the infertile soil cover.

Mangrove forest forms a discontinuous belt along the coastline of Darvel Bay and around the island, and is seen particularly at the estuaries of rivers and along saline mud flats. The forest mainly consists of species of the family Rhizophoracea.

Secondary jungle and coastal padang are common near the settlements.

The jungles of the area contain abundant wild life. Wild pig, deer, land turtles, are common and are a source of food. Monitor lizards may be seen in the streams and snakes of all species are common, though most are harmless. One large python was found measuring 26 feet 6" and had a girth of 1 foot 6".

The physiographic features of the area reflect the types of underlying bedrock. It is possible to divide the area into four physiographic belts. The largest of these is formed by the narrow ridge of the Silam-Beeston range itself, covering approximately 50 square miles. The range is largely composed of ultrabasic rocks. Heights along the ridge vary between 1000 feet and 2500 feet, culminating in Mount Silam 2950 feet, on the eastern end, and Mount Beeston 2500 feet, on the western end of the



PARTLY BASED ON VAN BEMMELEN'S WORK Fig 2.

area. Rock outcrops are plentiful along the range, principally in the stream sections. Above 2000 feet, on Mount Silam, access becomes difficult and often dangerous along the stream courses draining the precipitous flanks.

The northern slopes of the range pass into a belt of rolling hills, 100-500 feet high, that forms the northern boundary of the area. Quaternary alluvium and laterite tend to obscure the geology in this belt, the main part of which, appears to be composed of rocks of basic composition. Massive gabbro has been noted in the River Diwata and on Mount Beeston at the western end of this belt and also in the east, around Kennedy Bay.

The southern flanks of Mount Silam pass southward, into the third belt where low lying ground occurs, broken locally by ridges 100-1500 feet high, trending more or less parallel to the Silam-Beeston range. This belt, which extends from Kennedy Bay, to approximately 5 miles west of the River Diwata is composed chiefly of rocks belonging to the Chert-Spilite Formation of Cretaceous-Eocene age. Further to the west, on the south side of the range, the ophiolites may possibly be overlain by sandstone of probably Miocene age. This sandstone dips gently to the southwest in the form of a plateau.

Drainage of the Silam-Beeston range tends to be complex. The small streams draining the northern slopes of Mount Silam flow northward into the River Bole and Sapagaya systems; on the southern slopes of Mount Silam, the streams flow into Darvel Bay. The headwaters of the River Diwata, on the other hand, drains the northern slopes of the Mount Beeston. The main stream of the river flows eastward from the headwaters along the northern side of the range, but then at Mile 6 swings sharply to the south, cutting across the grain of the country rock. The River Puteh, draining the southern slopes of the range, joins the River Diwata at Mile 4, and the latter then flows southward to empty into Darvel Bay. The River Diwata drainage system is the most important and largest river system in the area.

PREVIOUS WORK AND ACKNOWLEDGEMENTS

The first reconnaissance survey of the Darvel Bay region was undertaken by Reinhard and Wenk in 1951, during the preparation of their Bulletin: "Geology of the Colony of North Borneo". The ultrabasic rocks of North Borneo were considered by these workers as being part of the Danau Formation, and of ophiolitic origin. They further considered that the rocks of basic and intermediate composition were of metamorphic origin and belonged to the "Crystalline Schists" of a presumed extensive basement complex, underlying the whole of North Borneo. Outcrops of this basement were confined to the northern and eastern part of the country and were thought to be of Pre-Cambrian and Upper Palaeozoic age (Reinhard and Wenk, 1951, p. 12).

Fitch, of the North Borneo Geological Survey Department in 1955, was the first worker to investigate the Segama and Darvel Bay area north of 4 degrees 37½' N. He established the main rock types and the general shape of the Silam-Beeston ultrabasic mass as shown on his 1:125,000 geological map. He concluded in his Memoir, 4, (1955) "The Geology and Mineral Resources of part of the Segama and Darvel Bay area", that the crystalline schists of Reinhard and Wenk were in fact "dioritic intrusive rocks, genetically associated with the ultrabasic intrusions and of Eocene age", (1955, p. 24). He separated the ultrabasic rocks and "diorite rocks" from the Danau Formation of Reinhard and Wenk and earlier workers and for the remaining volcanic and sedimentary rocks of the Formation, Fitch used the term "Chert-Spilite Formation" (1955, p. 24). Fitch (1955, p. 80), suggested that the 'diorite rocks' had been formed "by assimilation of crustal material by basaltic (gabbroic) magma". The lower periodotite rocks he envisaged as having been forced through the dioritic rocks (1955, p. 81), during the period of ultrabasic intrusion into the Chert-SpiliteFormation, probably Late Cretaceous or Eocene times. He further postulated extensive thrust faulting in the dioritic rocks of the Segama headwaters (Fig. 1) and the Mt. Ambun area. Dr. Kirk (1962, p. 10), suggested that these thrusts lie in a zone of thrusting, which extends southward into the Mostyn area and thus includes the Silam-Beeston area.

The field work on which this work is based was carried out under the direction of Naylor, Benzon & Co., Ltd., London and their local company in North Borneo-Borneo Mining Limited. Progress reports made during the survey 1962 in the Silam-Beeston area and the accompanying field maps, on a scale 1:25.000 and 1:500 are filed in the officies of the two companies. During the survey, which occupied about ten months, Ibans from Sarawak were used as general labourers and porters. A Base Camp was constructed 1½ miles inland along the River Diwata, and several temporary camps were made in the more innaccessible parts of the area. Access toward Mount Beeston becomes progressively more difficult along the course of the River Diwata and though the writer made several treks to this area, part still remains to be traversed beyond Mount Beeston.

ACKNOWLEDGEMENTS

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1. Manitoba. Canada.

CHAPTER II

COUNTRY ROCKS

General Statement

The intrusive igneous rocks of the Silam-Beeston range, have been emplaced into a varied assemblage of tectonically disrupted geosynclinal sediments and ophiolitic rocks, collectively referred to by Fitch (1955, p. 24), as "The Chert-Spilite Formation" of Cretaceous-Eocene age. The Formation occurs extensively in Eastern and Northern Borneo, and probably also in the Phillippines. In Kalimantan similar deposits, termed the Danau Formation, are probably of Cretaceous-Eocene age (Leichti, 1960, pp. 53-54). The Chert-Spilite Formation and related formations in neighbouring countries represent the early ophiolitic phase in the development of theEast Indian Geosyncline in these areas, as described by Van Bemmelen (1949).

Field Relations

Rocks of the Chert-Spilite Formation, in the Silam-Beeston area, outcrop in a belt 3 to 5 miles wide and 15 miles in length, along the southern part of the area, between the Silam Mountain and the northern coast of Darvel Bay. South of Mount Beeston and 6 miles to the west of the Diwata Valley, the Chert-Spilite Formation is mainly overlain by sandstone of?Miocene age.

On the northern side of the range, rocks of the Chert-Spilite Formation have a much more irregular distribution. Narrow lenses of these rocks were mapped between the peridotite of the range and the outcrops of

Table 1. Stratigraphy of the Silam-Beeston area, Darvel Bay, North Borneo.

Age	Sediments	Igneous Rocks
RECENT	Coastal and fluviatile alluvium, including Mangrove swamps along coast.	Calc tufa deposited in ultrabasic rocks.
PLEISTOCENE	High level alluvium on flanks of Silam mountain.	
MIOCENE	- unconformity - Sandstones and grey clays deposited in widespread sea.	Serpentinization and metamorphism of U/B rocks. Peridotite, dunite, pyroxenite, gabbroic rocks emplaced into Chert-Spilite Formation, during period of regional crustal shortening.
EOCENE and Late CRETACEOUS	- unconformity - Kulapis Formation. Radiolarian chert, graywhacke, marl, black shale, thin beds of sandstone and limestone interbedded with volcanic rocks in the sea trough or geosyncline.	Intrusion of peridotite magma into consolidated Chert-Spilite Formation, at close of geosyncline. Basalt, some spilitized green tuff deposited on geosyncline floor and interbedded with sediments.

gabbroic rocks (see Map 1 and 2) around the eastern part of Mount Silam (Map 2. 275.15 N., 469.10E) (275.80N., 470.80 E). Toward the west, gabbro predominates, and the ophiolites are obscure in the low lying ground.

In general the sediments and volcanic rocks of the Chert-Spilite Formation produce a varied topography of narrow valleys and long, sharp backed ridges, that may follow definite trend lines.

Rock Types

A great variety of rock types occur in the Chert-Spilite Formation in the Silam-Beeston area. Among the sediments, graywhacke appears to be the most abundant and occurs especially to the south of Mount Silam, where they form low hills. A description of the main rock types follows:

Graywhacke. The graywhacke occurs as massive beds and as thinly bedded layers in many of the stream sections that flow from Mount Silam. In the lower reaches of the streams the rock occurs in abundance as boulder debris.

Fresh graywhacke is normally dark brown to reddish grey, fine grained and strongly indurated. Quartz and felspar in the rock impart a mottled appearance. Veins of quartz and calcite also traverse the rock in many localities.

Radiolarian Cherts. Cherts are also widespread in the area but rarely outcrop in the stream sections. Boulders are however, common. In stream 11, the chert appears as a reddish brown rock and is often seen veined with quartz an chalcedony for example in these samples collected

$\frac{1}{2}$ mile above the river mouth (272.87N; 467.68E). Chert and quartzitic rocks also outcrop on higher ground for instance in stream 10, below the contact (Map 2, 273.50N.467.80E) where the rock forms a waterfall 5 feet high. Along the northern contact, between ultrabasic rocks and gabbroic rocks, $1\frac{1}{2}$ miles above Kennedy Bay (275.78N:470.80E), quartzites containing pyrite form a ten foot bluff on the hill sides. In the River Puteh, below the contact, quartzitic cherts also contain pyrite disseminations and in some of the pebbles collected hornblende and chlorite flakes were noted.

Argillaceous rocks. Graphitic shales outcrop in several localities in the area. A notable outcrop occurs on the spur, between streams 7 and 8, at approximately the 800 foot contour level (274.30N: 468.80E). The shales are black fissile and weathered. Black shales also outcrop in stream 9, at the contact of the Chert-Spilite Formation and the serpentinite (274.06N; 468.10E). Graphitic shales also are exposed along the southern contact of the serpentinite mass with the Chert-Spilite Formation at the headwaters of the River Diwata (See Diwata Traverse Map, Page 94). These mudstones and shales become progressively more streaked and massive as the contact is approached, in streams draining Mount Silam.

The volcanic rocks mainly consist of spilitic lavas, breccias, and green tuffs and normally show intense alteration by hydrothermal solutions, particularly near the contacts with the ultrabasic mass. The spilites are generally green, blue or grey in colour and many good outcrops of the rock type occur. In stream 7, at approximately the 800 foot contour level (274.25N; 468.78E), a 20 foot section may be seen in the eastern tributary where the spilites are associated with radiolarian chert.

In stream 8, epidote is disseminated through the spilite in samples taken from approximately the 1000 foot contour level (274.15N; 468.54E). Veins of quartz and calcite traverse the rock in many localities, for example in the River Silam (N 274.80; 470.52E), particularly near the contacts with the ultrabasic rocks. In general, the volcanic rocks become progressively more schistose or streaky in character as the ultrabasic rocks of the range are approached and may show intense hydrothermal alteration such as in streams 10, (273.60N; 467.68E), and 9, (274.06N; 468.10E).

In thin section the rock consists of a fine grained aggregate of feldspar needles and pyroxene crystals. Amygdales in the rock are frequent and are filled with calcite, chlorite and cryptocrystalline silica; pyrite is the usual ore mineral.

Contact Areas

There is a general tendency for the dips of the country rock to steepen as the peridotite mass is approached. This feature is especially seen in streams 9, 10 and 11 which drain the southern part of the range and which flow over the contact on high ground. Further, the spilite and mudstones of the formation become progressively more schistose and streaky in character and close to the contact have the appearance of being deeply altered by hydro-thermal solutions.

The contact along the southern margin of the ultrabasic mass was first observed in stream 6, at the 200 foot contour level (Map 2; 274.47N; 469.62E), where quartzites, streaked mudstones and graphitic shales are in contact with sheared serpentinites. Westward, the contact crosses the spur between stream 7 and 8. Boulders of quartz, spilite and an outcrop of graphitic shale were found on this spur, and the contact has been drawn in at the base of a steep rise (274.25N; 468.50E), at approximately the 1400 contour level. Toward the west again, sheared and blackened sediments occur at 1000 feet in stream 9, (274.06N; 468.10E), in a zone approximately 200 feet wide near the contact. In stream 10, at approximately the 1400 foot contour level, contact rocks are exposed at their highest level on Mount Silam. Here (273.60N; 467.65E), the schistose sediments and spilites were first observed at approximately the 800 foot contour, where the planes of schistosity lie almost horizontal; toward the contact the planes of schistosity steepen until they become vertical or steeply dipping to the northwest. The contact rocks are next seen in the eastern branch of stream 11, at 1000 feet (273.40N; 467.40E), where schistose spilites and quartzites are separated from schistose serpentinites by about 100 feet of boulder rubble. There appears to be very little difference in the height of the contact in the western branch of stream 11, where the contact was seen at approximately 1000 or 1100 feet. Spilite again forms the contact rocks in the small streams that flow between the River Puteh and stream 11, (272.95N; 467.07E) and (272.75N; 465.66E); the rocks appear highly altered by hydrothermal solutions. Toward the Diwata River the contact becomes obscure in low lying ground, and has been drawn in at approximately the 500 foot contour level. The contact was last noted at the headwaters of the River Diwata (see Diwata Traverse Map), where epidote hornfels and graphitic shales outcrop against schistose serpentinite. The contact probably runs westward toward Mount Beeston, from this last point, and the contact rocks may include Miocene sandstones.

The contacts on the northern side of the peridotite mass have only been observed at the eastern end of the range, and in the Kamut Valley. About a mile and a half above Kennedy Bay (275.80N; 470.80E), quartzites are exposed against schistose serpentinite rocks and mark the probable position of an extensive fault system trending north-east and east-west. This fault separates the Chert-Spilite Formation and gabbro rocks from the peridotite mass. Towards the west, as seen along the Silam Road, gabbroic rocks are exposed against the serpentinite and peridotite although at 275.40N; 469.10E spilites again form a narrow outcrop in a 50 foot section, in a northward draining stream. Here, the spilites are streaked and hydrothermally altered; calcite and quartz veins traverse the rock. Further to the west, the contact is obscure in low lying ground and concealed by fans of ultrabasic debris. Gabbro dykes become important in the stream sections and in general strike to the northeast. In the River Kamut, gabbro is thought to be the predominating rock type of the contact area. Massive gabbro is in contact with schistose serpentinite at N4°47': E118°05'.

More unusual contact effects are exhibited in several localities in the area. Toward the headwaters of the River Diwata, where the north-easterly flowing tributary joins the main stream at Mile 7½, (See Diwata Traverse Map); boulders of gabbro occur enclosed in sheared serpentinite. The gabbro boulders appear to be metamorphosed around their edges. Garnet was found in one of the specimens by Dr. Kirk (1962). These boulders are thought to have been brought up from depth along a thrust fault, which is now marked out by the straight course of the north-easterly flowing tributary.

In Rian Island, Darvel Bay, angular boulders of unfossiliferous limestone were found near Peg 13, enveloped in schistose serpentinite. The boulders are angular and appear unaltered. A similar occurrence was found at the southwestern headland of Saddle Island (L.I. 9), where grey shales and limestone xenoliths occur in dunite serpentinite. Baik Island, at the south western headland, also shows xenoliths of sedimentary rocks in schistose serpentinites. These broken off sediments of the Chert-Spilite Formation are thought to have been caught up in the sheared serpentinite during the emplacement of the Saddle Islands ultrabasic rocks.

The plateau, to the southwest of Mount Silam, has a general height of 500 feet but slopes to the southwest away from the ultrabasic ridge. This plateau is known to be formed of sandstone and is of possible Miocene age. The sandstones are thought to underlie a peneplain between the watershed of the River Bole and the River Diwata and may possibly rest on rocks of the Chert-Spilite Formation. Actual contacts of the sandstone with the ultrabasic rocks have not been observed. One specimen of sandstone containing angular fragments of serpentinite, (plate 13), was found in the headwaters of the River Bole near Mount Beeston, suggesting that the sandstone may be present locally on the northern side of the range.

CHAPTER III

THE INTRUSIVE IGNEOUS ROCKS

General Statement

The Silam-Beeston ultrabasic mass is one of a number of ultrabasic bodies, which are known to occur in the East Indian belt of young Tertiary ophiolites that stretches from the Philippines down through North Borneo to the Celebes. In the eastern part of North Borneo ultrabasic rocks are known to outcrop in the following areas: on the offshore islands of Banggi and Malawali, near Kudat; east Marudu Bay, around Pingan-Pingan; the Ranau district; the Labuk Valley area; the Kinabatangan and Segama Valley area; and the Darvel Bay area. In general the ultrabasic rocks have been intruded into the lavas and sediments of the Tertiary geosyncline.

The ultrabasic rocks of the East Indian geosyncline are generally associated with variable amounts of basic and intermediate rock types. In North Borneo, these associated rock types probably occur in equal amounts to the rocks of ultrabasic composition. Large masses of gabbroic rocks are known to outcrop in the Philippines and in the Labuk and Segama Valley areas, as massive rock and as dykes. In the Silam-Beeston area, gabbroic rocks occur extensively on the northern side of the peridotite mass and are intrusive into the rocks of the Chert-Spilite Formation.

Fitch (1955, p. 24), described these basic rock types as being of "dioritic" composition. Kirk (1962), during his survey of the Darvel Bay and Semporna areas, considers that most of the dioritic rocks of Fitch are actually amphibolites or gabbroes in character.

The intrusive igneous rocks of the Silam-Beeston range, cover an area of approximately 80 square miles. They form a belt of rocks twenty miles long and approximately four miles wide, trending in general northeast. The peridotite rocks occur along the southern part of the belt and the gabbroic rocks are mainly confined to the northern side.

A description of the chromiferous ultrabasic rocks of the Saddle Islands is included in this report. These islands are believed to represent a separate intrusive, arcuate shaped, sheet-like mass, in rocks of the Chert-Spilite Formation. The islands are strung out over a distance of five miles and have a general strike in the bay of north-west. Part of the same intrusion is also found on the mainland close to Silam village, (see Map 1), (273.10N; 469.10E).

THE ULTRABASIC ROCKS

The term "Peridotite" is a general term used for those rocks which contain only olivine and pyroxene as their chief mineral constituents. Such rocks are divisible into intergrading varieties according to the proportion in which olivine, and the orthorhombic and monoclinic pyroxenes are present in the rock. In the Silam-Beeston area four varieties have been distinguished. They are:

(1) DUNITE. This rock consists of not more than 5% pyroxene, and not less than 95% olivine. The pyroxene component in the area is usually enstatite.

(2) LHERZOLITE. This rock contains olivine and the two types of pyroxene mineral, that is, the monoclinic and orthorhombic varieties.

(3) HARZBURGITE. This rock type predominates in the area, and forms the bulk of the Silam Mountain. The rock consists of 5 to 60% enstatite. As the pyroxene content increases the olivine content decreases.

(4) PYROXENITE. This rock is composed wholly of the mineral pyroxene, usually clinopyroxene in the area, or of pyroxene with not more than 5% olivine. These rocks are found massive and as dykes in the area transecting the other three.

The ultrabasic rocks in the Silam-Beeston area form a belt 3-4 miles wide and 17 miles long, along the northwestern coatline of Darvel Bay. The ultrabasic rocks trend, in general, to the northeast, and form the highest ground in the area overlooking the bay.

The general shape of the outcrop is lenticular. In detail the outcrop thickens and thins rapidly along its length. At the eastern end of the range, above Kennedy Bay, the peridotite outcrop is a mile wide, but rapidly narrows to a width of ½ mile, where the Kennedy Bay, Silam Road, cuts across the range (275.25 N; 470.15 E). Further to the west, the outcrop rapidly broadens to its maximum width of three miles about Mount Silam, but then narrows again to a two mile width at the River Diwata. Approximately one mile to the west of the River Diwata the outcrop widens to two miles and from there attenuates rapidly to the west where it is thought to lense out to the east of Mount Beeston.

The pattern of outcrop on the Saddle Islands is similar to that seen on the range. On Laila and Saddle Islands, the outcrop measures approximately a quarter of a mile in width, but narrows rapidly to the northwest and southeast to outcrops of less than 400 feet in width, as seen in islands 3 and 6.

The most abundant rock type in the Silam-Beeston igneous complex is harzburgite; it forms the bulk of Mount Silam and the hills to the west of the River Diwata, along the range. Much of the serpentinite on the northern and southern margins of the intrusion are believed to have been derived from rocks of harzburgite composition. Within the massive, unsheared harzburgites, narrow dunitic segregations occur which show a general concordant relationship to the internal structure in the surrounding harzburgite rock.

Pyroxenite, occurs massive on the flanks of Mount Silam and as dykes cutting the harzburgites and dunites, particularly in exposures on the Saddle Islands. That the pyroxenite is younger than the harzburgites and dunites locally, can be shown by the numerous exposures of the pyroxenite dykes of the Saddle Islands possessing chilled edges.

DUNITE

Dunite represents approximately 5% of the known ultrabasic rock types in the Silam-Beeston area.

The presence of dunitic segregations, within large masses of harzburgite, appears to be typical of the ultrabasic masses in North Borneo. Dunite was recognized, in massive rock, on Banggi Island, in the Kapitangan ultrabasic mass, as thin lenses; and in the Porog harzburgites, where one inch to two hundred feet wide lenticular masses of dunite occur. On Mount Silam, the dunitic layers are parallel in strike and dip to the planes of foliation in the harzburgite. The segregations never attain significant size on the mountain; but occur several hundreds of feet wide, in outcrop, locally, in the Saddle Islands.

On the Silam Mountain, dunite was noted in many localities, the most important of which are as follows:

At the headwaters of stream 14, at approximately the 1800 foot contour level (273.85 N; 466.65 E), dunite occurs as 2-3 feet thick layers striking to the northeast, across the north flowing stream. These layers strike concordantly to the planes of foliation in the surrounding harzburgite. Dunite rocks have also been found in the River Hitam (stream 12), one half mile from its junction with the Sapagaya River (275.30 N; 468.38 E), (LS.42). The dunite layer is here associated with dunitic rocks in which the pyroxene content is approximately 5%. In stream 11, a quarter of a mile from the contact of peridotite and ophiolites, layers of dunite, 1-2 feet, thick strike N48E across the direction of the stream (273.45 N; 467.30 E). Further to the west, in the River

Puteh, a thin lense, 2 feet 6 inches wide, has been recognized at approximately the 1000 foot contour level (273.35 N; 465.70 E). This lense strikes N53E concordantly to the structures in the surrounding harzburgite. Similar dunitic layers occur in the same stream section containing fine grained pyroxene and thin stringers of spinel, visible in hand specimen (LS. 66). Dunite has also been recognized in the River Diwata as narrow segregations (Fitch, 1955, p. 57), in the main stream, and also a $\frac{1}{4}$ mile up a small southwesterly flowing tributary of the River Diwata close to the peridotite-gabbro contact, near Mile 6 (see Diwata Traverse Map).

The dunite layers have a much greater thickness in the Saddle Islands exposures. They contain important concentrations of chrome ore. Reliable dips and strikes taken of the structures in the dunite suggest that the layers are vertical. Noteworthy outcrops in the islands of dunite serpentinite are as follows:

1. Kalung Island. (see Map 1, and Fig. 11). Situated one and a half miles to the southeast of Giffard Island and one mile to the southwest of Baik Island, in Darvel Bay, the island is 600 feet long and 300 feet wide, and wholly composed of dunite serpentinite. The rock is generally massive in character, though joint patterns are closely spaced. Generally the rock is a buff colour, and weathering of the surfaces has penetrated deep, so that fresh dunite serpentinite is rare at the surface. Chrome ore, as single grains or as thin layers, stand out vividly in the rock. Layering in the dunite serpentinite shows that there are two directions on the island: N70-80W along the eastern side of the island; and N50-75E along the southwestern part of the island. Shear zones cut the rock at the southwestern corner of the island N30-40W,

and indicate the position of minor faults; these zones are approximately 10 feet wide and dip steeply to the south.

2. Rian Island. (see Map 1). This island (no. 3 in the Saddle Islands group) lies between Giffard Island and Laila Island. It is 300 feet long and 50 feet wide and is composed entirely of dunite serpentinite. The rock is heavily slickensided and the slickenside directions indicate a complicated series of movements in an upward direction. Some of the sheared serpentinite has been pulverized, but the planes of schistosity, in general, strike to the northwest, with steep dips to the southwest.

3. Laila Island. The southern part of this island only, is composed of dunite serpentinite. The irregular shaped southern peninsula of the island is 900 feet long and 50-300 feet wide and forms the largest single outcrop of dunite serpentinite in the Silam-Beeston area. Exposures along the beach section show the dunite serpentinite to be a massive rock on the southwestern headland, and schistose elsewhere. Vertical layers of chromite on the headland in massive rock strike in a similar direction to Ore Zone IV, Kalung Island (see Fig. 11), that is, N50-60E.

4. Islands 5, 7 and 9 are also composed chiefly of dunite serpentinite, part of which is schistose. The layered structure of the massive rock, similar to that seen on Kalung, and Laila Island, has been completely destroyed by the shearing.

In hand specimen the dunite serpentinite weathers a light buff colour, on the surfaces of which the accessory chromite and magnetite is conspicuous, (L.I. 92, Island 3). The texture of the rock, when massive, is compact and has a deeply altered appearance. Fresh specimens of the dunite serpentinite are rare, though one specimen was collected from the western side of Island 7, and has a dull black colour (L.I. 10). In a specimen from Laila Island (L.I. 58), streaks of limonite traverse a relatively unweathered rock; in Island 3 (Rian Island), and Island 6, the dunite serpentinite is streaked with magnesite.

Opposite Peg 8, on Rian Island, 12 feet up the cliff face, quartz and gold coloured mica with some hornblende occur in a thin 6 inch wide vein cutting the rock. Aragonite crystals were noted on Island 6 in some of the cavities in slickensided dunite serpentinite and may possibly indicate the high pressures to which the dunite was subjected.

In thin section the olivine shows nearly complete or advanced alteration to serpentine minerals. Original rock structures have generally been destroyed and a mesh texture superimposed (L.S. 33, River Diwata); (L.S. 16, Mount Silam). Kernels of fresh olivine, where they occur are probably of forsterite composition.

Accessory chromite is widely scattered in the rock, or may occur as discrete layers. Individual grains are compact, (L.S. 64, Island5). In the latter specimen the rock is completely altered to mesh antigorite and shows the chromite grains altered to magnetite around their edges. In specimen L.I. 28, from Island 8, the grains of chromite have a lenticular shape, and their axes are arranged parallel. Magnetite is a common accessory mineral in the dunite serpentinite, and has a very irregular shape. In one specimen from the Hitam River (L.S. 42), (275.30 N; 468.38 E) coronas of chlorite occur around the edges of the grains of magnetite. Talc and calcite are also common accessory minerals.

HARZBURGITE AND LHERZOLITE

As in most of the ultrabasic outcrops in North Borneo, harzburgite forms the most important rock type, together with the serpentinite rocks derived from them. Lherzolite occurs only as thin segregations within the main masses of harzburgite.

In the Silam-Beeston range, harzburgite rocks are best seen over Mount Silam, where they extend for ten miles in a northeast direction, (see Map 1); the maximum width of the belt is three and three-quarter miles. The pattern of the outcrop is lenticular, (see Map 1). The harzburgite tends to be massive at the centre of the outcrop where a well developed cuboidal system of jointing is characteristic of many outcrops. Fine examples of this joint system were seen toward the head-waters of stream 9 (274.10 N; 467.85 E), and stream 10 (273.85N; 467.65 E), and stream 11 (273.50 N; 467.10 E), (273.25 N; 467.20 E), between 1500 feet and 2000 feet, on the southern side of the mountain. On the northern side this regular joint pattern was seen in the headwaters of the River Kamut (273.75 N; 466.80 E), (274.10 N; 467.25 E).

The harzburgite in outcrop is generally a distinctive rock on account of the mineral pyroxene, which forms lustrous insets in the surfaces. The pyroxene mineral produces a characteristic foliation structure in the harzburgite. In general, the harzburgite rocks are fine to medium grained. As the pyroxene content decreases, harzburgite grades into dunitic type rocks.

Progressively, toward the north and south contact areas, the massive harzburgite becomes increasingly more slickensided and the joint and foliation structures becomes less evident. Serpentinization of the rock also increases, and at the thrust contacts the harzburgite has been completely converted to serpentinite schists, (see Map 1).

Peridotite rocks - harzburgite and lherzolite - also occur in the Saddle Islands. Harzburgites form the northern halves of Laila Island and Saddle Island, and the whole of Baik Island, opposite Kennedy Bay. They are generally heavily slickensided and serpentinization is advanced.

The mineralogy of the unaltered harzburgite is simple. The rock consists principally of magnesian olivine, and the orthorhombic pyroxene—enstatite; diopsidic augite may sometimes be present. Chromite and magnetite are common accessories. It is not possible to distinguish the harzburgite from the lherzolite in outcrop.

In hand specimen the rocks are fine to medium grained, blue-grey, black, or reddish brown in colour. The pyroxene crystals are visible as lustrous insets and frequently impart to the rock a strong foliation, (Plate 12). The pyroxene content of the rock varies considerably from place to place; in those stream sections which show a strong foliation structure, such as in the Kanut River, the pyroxene content may amount to approximately 60% of the rock. Weathered surfaces are typically corrugated, light to dark brown in color, the latter colouration being caused by a crypto-crystalline material, white in reflected light, which changes abruptly to the normal colour in unweathered rock.

In thin section, the olivine forms equidimensional grains, 1–2 mm. across, which are more or less converted to serpentine or antigorite. Relict olivine at the centres of the crystals are colourless

(L.S. 46), were taken to be of forsterite composition. One specimen from Mount Silam, in stream 10 (L.S. 10), showed granules of magnetite outlining the boundaries of the former olivine crystals.

Generally the pyroxene is of the non-pleochroic enstatite. The mineral occurs as anhedra, 2 to 5 millimeters across, scattered singly in the rock, or as crystals showing a common orientation in thin lenticular segregations. Some of the crystals in thin section show an undulose extinction (L.S. 61). Bastite fibres are developed in many of the samples taken from stream 10, above 2000 feet, and when the fibres are parallel to the 010 the crystals possess a marked pearly or metallic lustre as in stream 11 (L. S. 92).

Chromite occurs as an accessory mineral in all the harzburgites. The mineral occurs as compact grains with angular or embayed outlines characteristic of minerals of early crystallization, or as interstitial, irregularly shaped crystals containing minute inclusions of silicate minerals, thus indicating a later crystallization. Spinel occurs in dunitic harzburgite, at 1000 feet, in the River Puteh section and forms blebs of up to one inch across in the rock, striking parallel to the direction of the harzburgite foliation (L.S. 67; 272.97N; 465.60 E). In L.S. 55, from the same river, the blebs of spinel are faintly green in colour, and surrounded by a white opaque mineral which has low polarization. In L.S. 46, the spinel, in thin section, is a deep brown colour and occurs in sub-ophitic relationship to the pyroxene and olivine minerals of the harzburgite.

Rocks of lherzolite composition appear to form thin segregations within the main mass of hazburgite on the Silam Mountain, but their actual distribution is obscure.

The essential constituents of a lherzolite found in the River Diwata (L.S. 64), are olivine and the orthorhombic and monoclinic pyroxenes; the pyroxene forms less than 20% of the rock by volume. L.S. 47 (274.50 N; 465.40 E), contains roughly 25% of mixed colourless orthorhombic and clinopyroxene. Individual plates of pyroxene measure 4 millimeters across and contain abundant inclusions of olivine. In thin section the olivine is almost completely converted to mesh antigorite; the diopside and enstatite has altered to antigorite and chlorite.

PYROXENITE

Pyroxenites form approximately 5% of the known rocks exposed at the surface in the Silam-Beeston area. On the main range the rocks are widely scattered and generally occur as massive rocks or as dykes cutting the harzburgite. In outcrops of the Saddle Islands, pyroxenite occurs as thick dykes, the chilled margins of which may be seen in several localities. The dykes, in general, appear to be vertical or steeply dipping in the schistose serpentinite.

On Mount Silam, notable outcrops are as follows:

1. Diwata Valley. Pyroxenite occurs in the stream section at several localities, approximately at Mile 7½ along the river. The pyroxenite appears to be intrusive into sheared serpentinite and in one exposure the pyroxenite is brecciated. Kirk (1962), noted pyroxenite at this locality overlain by tremolite amphibolite, and that the contact between the two rocks was sharp. From this last outcrop, for a quarter of a mile upstream, brecciated pyroxenite occurs in the stream section in serpentinite. Along the course of the northeasterly flowing tributary of the

River Diwata at 272.50 N; 463.00 E, a ten foot wide dyke of pyroxenite cuts the serpentinite, and shows excellent flow layering parallel to the walls of the dyke.

2. The most important outcrops of pyroxenite in the Saddle Islands are as follows:

1. Giffard Island. Pyroxenite is exposed in an outcrop 250 feet wide and 400 feet long along the beach sections of the island. Contacts of the dyke have been observed on the southeast corner of the island. The pyroxenite is massive toward the centre of the island, about Peg 3, and probably represents the centre of the dyke. Slickensided and schistose pyroxenite tend to predominate toward the northern and western margins of the island. At the northern and southeastern headlands an interlayered relationship of the dunite serpentinite and the pyroxenite may be seen (Plate 15). The general direction of the layering is N30E with a moderate dip to the southeast 40-60 degrees (Peg 9). The strike of the layers are thought to be parallel to the walls of the dyke, as in the Diwata Valley (272.50 N; 463.00 E), so that the dyke cuts the dunite serpentinite in a northeasterly direction. Individual layers in the dyke range from a few millimeters to a foot or more (Peg 14), but along their strike they can be followed for only a few inches or feet. The dunitic rock between the pyroxenite layers is often unsheared (Plate 15), and often contains chromite grains which are aligned parallel to the walls of the layers (L.I. 24).

2. Island 6. Massive pyroxenite occurs along the intertidal regions on the southern shore of the island. The rocks are characteristically dark green and possess a vitreous lustre. Toward the southern end of

the island they attain their maximum thickness of twenty feet. Chilled margins have been observed on the small bluff of the island; the chilled rock is white-green in colour and in thickness varies from one to three inches. The contact serpentinite rocks have been invaded with magnesite ore. Gabbro has later intruded the pyroxenite dyke and metamorphosed the pyroxenite rock locally (Plate 9).

3. Laila Island. A dyke of pyroxenite forms a prominent rib 7 feet wide on the eastern shore line of the island, approximately 500 feet from the southern headland. The dyke is intrusive into sheared serpentinite and can be traced along the strike of N50W for 50 feet, from the shore to the cliff face. Chilled margins, one to two inches thick, may be seen at the sides of the dyke dipping vertically; they have the same bleached white-green appearance as in the outcrops on Island 6 and Giffard Island. The schistose serpentinite in contact with the dyke is impregnated similarly with nodules and veins of magnesite. The ore is thought to have been derived from the decomposition of serpentinite during the period of pyroxenite intrusion.

In hand specimen the rock is fine to medium-grained, granular in appearance and in samples from the Saddle Islands (L.I. 50 - Giffard Island), the rock has a marked vitrous lustre and is dark to pale green in colour. Iron oxide frequently streaks the rock. A pegmatite facies occurs in a small exposure on the mainland, where the most northerly outcrops of the Saddle Islands ultrabasics occur, opposite stream 9 (273.25 N; 469.10 E). Here, the pyroxenite is sheared and intrudes the serpentinite schist derived from dunite. Individual crystals of pyroxene measure 3-6 inches across and, as in most of the specimens taken from the

Saddle Islands, features of cataclasis are common particularly on the dyke edges.

In thin section, the rock may consist almost entirely of the monoclinic pyroxene-augite (L.I. 40 Laila Is.), with an extinction angle of approximately 43 degrees, or may range through mixed monoclinic pyroxene - diallage, diopside and hypersthene (L.I. 36) - to a rock containing almost pure hypersthene (Fitch 1955, p. 59). L.I. 86 consists of twinned hypersthene crystals with less than 5% olivine. The ferroan diopside-diallage is frequently made conspicuous in hand specimen by its pearly or metallic lustre (Stream 10, L.S. 43). In thin section the rock generally shows a granular texture, though in one slide (L.S. 33), some of the crystals are poikilitically enclosed in larger crystals. Individual pyroxene crystals are ragged in appearance, cracked (L.I. 85), and show strained extinction (L.I. 86). Some of the crystals are torn apart down their cleavage. In some of the rock slides, made from the Giffard Island pyroxenites, part of the pyroxene grains have suffered granulation. Chromite is the usual accessory mineral as in Stream 10 (273.75 N; 467.75 E). The rock may, in part, be converted to serpentinite and chlorite; L.I. 36 contains accessory limonite in streaks.

SERPENTINITE

In the ultrabasic rocks described above much of the olivine component of the rocks and, to a lesser extent, the pyroxene, have been converted to minerals of the serpentine group. Rocks in which this alteration is complete, or nearly so, are dealt with separately, here, under the heading "serpentinite". Serpentinization in the area has mainly affected, therefore, the dunite and harzburgite rocks. A detailed discussion on the origin of serpentinization is beyond the scope of this work, but it is pertinent to point out the general distribution.

Serpentinization is most intense along the southern and northern margins of the peridotite mass. Progressively from the contact areas toward the centre of the Mount Silam serpentinization decreases. Along the contact areas the serpentinite is schistose in character and mark the position of the extensive thrust faults. The control for the serpentinization appears to have been these large thrust planes - the North and South Silam Thrusts - which acted as channels along which the hydrous fluids effecting serpentinization flowed. Faulting and shearing appears to have occurred preferentially along the zones where serpentinization was complete.

Serpentinization has greatly affected the dunite rocks of the Saddle Islands. The serpentinite is generally highly weathered and schistose in character, as seen on Rian Island, and Island 8 and 9. In some cases the serpentinite has been pulverized. Where serpentinites juxtapose gabbro intrusions in the Saddle Islands, such as at the southwestern corner of Giffard Island and the southwestern headland of

Island 3, silica has invaded the joints and forms a resistant network or boxwork in the serpentinite. On the southwestern headland of Laila Island, and on Rian Island, opaline silica traverses the rock in quarter inch veins and carry granules of chrome ore (Peg.5 L.I.42,Rian Island.);(see also Plate 11,Laila Island.). These chromite grains are thought to have been derived from the serpentinite during a period of metamorphism.

Silicification of serpentinite rocks are known elsewhere in Borneo and in other parts of the world. Kirk (1960,p.117) describes examples from the Umas Umas Valley to the south of the Silam-Beeston area, in which the serpentinite has been completely converted to silica. Weaver (1949), described a similar metamorphic effect in the serpentinites of the Coast Range of California. He states that silicified serpentinites are common to highly faulted areas. Farquhar (1958), has also described silicified serpentinites in the Taita Hills, Kenya, and suggests that they have been derived from hydrothermal fluids invading the rock during a period of regional metamorphism.

Veining by silica and limonite, as seen in the serpentinites of the Saddle Islands, appears to be an intermediate stage to the complete conversion of the rock to silica and silica-carbonate rocks. It seems likely that the veins have been derived similarly from hydrous fluids, during regional metamorphism.

In hand specimen the massive serpentinite is a pale green to dark-grey colour and frequently has a waxy appearance (stream 10 273.65 N; 467.65 E). The palest serpentinite rocks occur on the flanks of the Silam Mountain, between 1600 and 2000 feet, in streams 9, 10 and

11 and also in the Kamut River, (274.05 N; 466.50 E) (274.45 N; 467.05 E). The rock is massive in character, yellowish-green or dark green in colour as in L.S. 31 (273.50 N; 467.15 E), and has a waxy lustre as in examples from stream 10, (L.S. 46: 273.70 N; 467.68 E). In streams 9, 10, 11, the Kamut River, and in a small tributary of the River Diwata at Mile 6, this massive pale serpentinite possesses a marked lineation structure, caused by the alignment of minute lenticles of chlorite with admixed magnetite.

The sheared and slickensided rocks are blue grey in colour and picrolite coats the slip surfaces. Asbestos fibre and talc are also common in the schistose rock.

In thin sections made from serpentinites derived from dunite, the rock consists of a mass of serpentine minerals and possesses a mesh or fibrous texture. Recognisable pseudomorphs of olivine are only occassionally seen. In L.S. 56, the pale green rock shows approximately 10% relict pyroxene; the crystals show a marked schiller texture and possibly indicate former orthopyroxene. In L.S. 37, from the flanks of Mount Silam, the pale peridotite has a streaky appearance, is chromite free, and contains approximately 5% relict pyroxene showing the bastite fibres. Ghost structures of olivine were recognized in L.S. 15. In rocks derived from Harzburgite actinolite and chlorite are common. Chlorite is common in the palest serpentinite rocks (L.S. 37; 274.08 N; 467.96 E) and the conspicuous lack of chromite in these rocks suggests that the ore has been broken down during serpentinization leaving residual magnetite. Slides could not be obtained from the friable slickensided and schistose rocks near the thrust contact areas.

GABBROIC ROCKS

Gabbroic rocks are typical representatives of Alpine Ultrabasic Associations (Benson 1926; Thayer 1960). Generally, the gabbroic rocks in peridotite-gabbro complexes occur in subordinate amount to the peridotite (Kaaden 1960, p. 117), but belong to the same igneous cycle.

Though the boundaries of the gabbro outcrop have not been mapped with certainty on the northern side of the Silam-Beeston range, it seems certain that these rocks occur in at least equal amounts to the harzburgite and serpentinite rock types. The gabbro has been intruded into rocks of the Chert-Spilite Formation together with the peridotite rocks, when the latter were in a solid condition (v.d.Kaaden, Muller 1953, pp. 59-78).

The gabbroic rocks occur in a broad belt mainly along the northern and eastern sides of the ultrabasic mass. The belt is 22 miles long and has a possible width of 1 to 1½ miles. In general the gabbroic rocks form the foothills of the range and locally form important ridges, for instance at the entrance of Kennedy Bay which attains a height of 500 feet, Mount Beeston, 2590 feet, is composed of gabbroic rocks. The northern boundary of the gabbro, between the Segama River and the Mount Silam, is thought to be irregular; several narrow ridges have been crossed in the area but their exact location was not ascertained. These ridges are of quartzite and spilite, and appear to form lenses within the belt of gabbroic rocks (see Map 1); the lenses appear to become more important northwards of the range.

The gabbro occurs as massive rock and as dykes, in swarms, on the northern margin of the ultrabasic rocks, particularly in the serpentinite schists. To a lesser extent they occur along the southern border of Mount Silam ultrabasics in the serpentinite schist zones. The dyke swarms show a marked parallelism to the general elongation of the ultrabasic mass and to the structures in the harzburgite. Numerous dykes occur in stream 13 (275.50 N; 468.00 E), measure 10 to 20 feet in thickness and in general strike, to the northeast. Chilled margins may be seen (275.50 N; 467.85 E), and the contact serpentinite rocks are frequently iron stained. The dykes are generally steeply dipping; in the stream 13, several dykes were found to be dipping to the south and southeast 60-80 degrees. Swarms of gabbro dykes also occur in the schistose serpentinite in the Kamut River (274.40 N; 466.30 E). These dykes vary in width from 15 to 25 feet and strike east-west. They are generally coarse grained and possess a well developed lineation structure. On the southern side of the range, dyke swarms occur in the Silam Road cuttings (275.20 N; 470.40 E). These dykes also possess chilled edges and are coarse grained. They strike roughly east-west, with a vertical dip and, in thickness, range from 2 feet to 5 feet. Some of these dykes are brecciated in the highly sheared serpentinite. Thin dykes also occur in the River Silam and are strongly lineated showing chilled edges (274.85 N; 469.84 E). The dykes trend roughly east-west with a vertical dip in slickensided serpentinite and, in thickness range, from 2 feet to 5 feet. Similar occurrences also occur in stream 6 and 7 (274.50 N; 469.60 E), and

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO.

Plate 1. Hornblende gabbro, showing the well developed lineation structure, trending northeast, Silam Harbour, Darvel Bay, North Borneo.

(274.50 N; 468.95 E); and in stream 11 (273.05 N; 467.65 E). In the dunite serpentinite rocks of the Saddle Islands the gabbroic dykes are less numerous and where they occur are generally never more than one foot in width. The largest occurrence may be seen on Island 6, where a gabbro dyke cuts serpentinite schists and pyroxenite, and is 6 feet thick. The dyke is also strongly layered (Plate 9). Thin gabbro dykes also occur on the peninsula (273.15 N; 469.15 E), striking east-west and dipping vertically in the schistose serpentinite.

Massive gabbro outcrops are best seen on the beach sections on the eastern side of Kennedy Bay (274.50 N; 471.75 E). The rocks are strongly lineated and layered, though strike directions tend to be erratic. The gabbro forms the northwest-southeast trending ridge overlooking the bay. Excellent sections of massive gabbro, strongly lineated, occur in stream 1 (275.15 N; 471.25 E); inclusions of spilite form a lense in the gabbro rocks approximately ½ mile from the river mouth. Gabbro boulders were also seen on the hill at 1000 feet, which forms the termination of the Silam-Beeston range on the east (275.80 N; 471.47 E). Massive gabbro rocks, highly weathered and slickensided occur at Mile 3, along the Kennedy Bay Road (275.85 N; 471.15 E), (275.20 N; 469.75 E), where the gabbro is brecciated and weathered. This faulted gabbro is thought to mark the approximate position of an important thrust fault separating the peridotite of the range from the massive gabbro of the north. Outcrops of the gabbro become rare in the low ground on the northern side of the range, although abundant boulder debris was noted.

Gabbro in massive form is next encountered in the Diwata Valley at Mile 8, (See Diwata Traverse map). The massive gabbro extends for approximately a further two miles toward the headwaters of the River Diwata. Contacts with the serpentinite are faulted.

The gabbroic rocks of the Silam-Beeston range are conspicuously layered or streaked in hand specimen by the principal dark mineral of the rock-hornblende. The feldspar tends also to be grouped into narrow lenticles, the direction of which, imparts a strong lineation occasionally to the rock. The trend of the lineation parallels the strike of the layering. The rock is light to dark grey, or in the case of the more hornblendic types the rock may be green-black or black, in colour.

Though most hand specimens, away from the faulted areas, appear massive under the microscope, for instance at the entrance to the Silam Harbour (275.10 N; 471.20 E), the rocks are composed of shattered crystals. Fitch (1955, p. 65), considered this to be evidence of movement of the rock when in a semi-solid condition. The essential minerals are the calcic Felspar-labradorite, hornblende and minor amounts of olivine and pyroxene. The plagioclase occurs as anhedra 1-1½ millimeters across and shows frequent twinning on the albite and twinning laws. The hornblende may be of the colourless iron poor type, or of the green-brown variety, or of the red, soda rich types. The hornblende forms streaks and layers and small pods of up to 3 centimeters thick in the white metrix of feldspar. The pyroxene is normally of the colourless monoclinic variety with z/c approximately 36 degrees. The pyroxene is normally mixed with the hornblende and is indistinguishable in hand specimen.

In L.I. 71, much of the colourless orthrombic and monoclinic pyroxene was found to be altered at the rims to hornblende. Olivine generally occurs in accessory amounts and as serpentinized anhedra in the rock. Other minerals may be present such as garnet. Kirk (1962), found garnets in specimens taken from the River Diwata at Mile 7½. Dr. Kirk also found prehnite in one of the specimens taken from the same locality (see Diwata Traverse map). Prehnitization is thought to be the result of metamorphic (hydrothermal) activity (G.v.d.Kaaden 1960, p. 117) probably during the period of serpentinization. Pyrite is a common accessory mineral, for example in specimens from the Kamut River.

CHAPTER IV

STRUCTURE OF THE ULTRABASIC MASS

General Statement.

Several authors (Van Es, 1920; Brouwer 1925; Staub 1928; Reinhard and Wenk, 1951, p. 27) who discuss the regional structures of the East Indies, show that the important Tertiary trend lines of Sarawak, and Central Borneo cross North Borneo in a general north northeast direction. These trend lines form distinct morphological features and though there is a general northeasterly trend in North Borneo many branch lines occur. The general regional trend, however, continues on toward the Philippines.

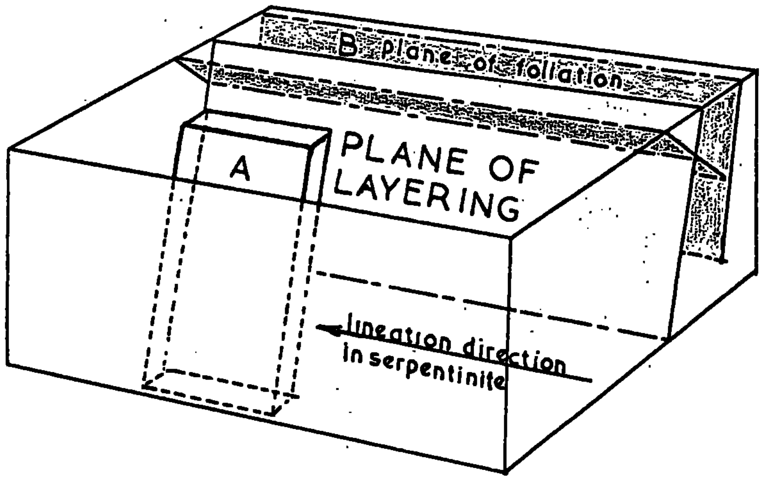
The chromiferous ultrabasic rocks of the Silam-Beeston Range show a general northeast trend and a broad concordance of its tabular or lensoid shape with the trend lines of the country rock Chert-Spilite Formation. In general the peridotite-gabbro complex of the range is a typical Alpine Ultrabasic intrusion (Turner and Verhoogan 1951, p. 240). This tabular, or sill-like mass characteristically thickens and thins along its length (Taliaferro, 1943, p. 153).

The structures seen in the peridotite-gabbro complex of the Silam-Beeston Range are of two kinds:

(1) Igneous or Primary Structures, which resulted from intrusion and crystallization of the mass; and

(2) Tectonic or Secondary Structures created by later deformation of the basic and ultrabasic rocks during their emplacement as a 'solid rock' mass into higher levels of the country rock Chert-Spilite Formation, during the Miocene orogeny.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, N.BORNEO.



Diagraml. To show the relationships between the layering 'A', and 'B' the foliation in the peridotite rocks of the Silam Mountain. Note that the planes of foliation may parallel or intersect the planes of layering. The general direction of lineation in the serpentinite is also shown; the axis of which is horizontal.

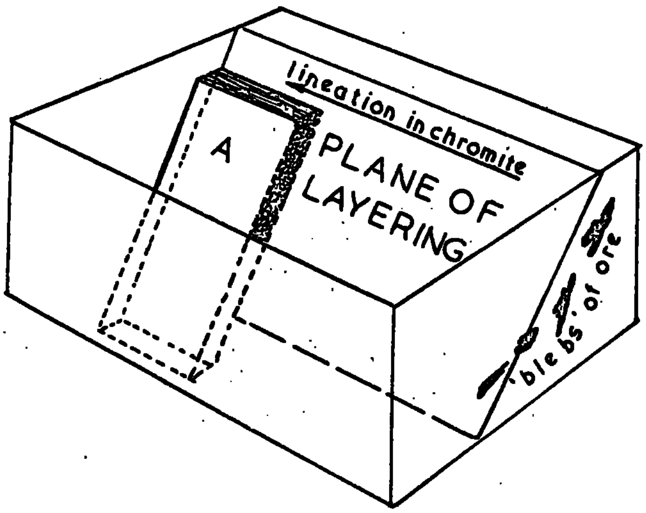


Diagram 2. To show the general relationships of the structures seen in the chromiferous dunite serpentinites of the Saddle Islands, Darvel Bay. The axis of lineation in the Tabular deposits is horizontal; and the Irregular deposits may lie at any angle in the massive dunite serpentinite.

<u>(1) The Primary Igneous Structures.</u> In the field three distinct types of primary structures have been mapped in the area. They are: (a) Layering; (b) Foliation; and (c) Lineation. Layering and foliation are planar features and because there is a close association of the two in the field and because there is often a gradation of one into the other, the two structures often present difficulties in field mapping (Thayer 1960). This complication arises from the fact that the planes of layering are frequently parallel to the planes of foliation. Locally the two planes may show different strikes and intersect along their dips at various angles. Thayer pointed out (1960), that the layering and foliation may be developed separately, and independent of the lineation. The lineation seen in the gabbro rocks appears to be a primary rock structure, but the lineation in the massive serpentinite of Mount Silam is a feature developed during the serpentinization of the rocks.

<u>(a) Layering.</u> Wager (1953, p. 335), defined a layered series of rocks as an "igneous complex which can be separated by structural or mineralogical criteria into a succession of sheets lying one upon the other". The individual sheets or layers as seen in the peridotite rocks of the Silam-Beeston area can be separated from the foliation structure and can be used as a separate mapping feature. Individual layers, are clearly defined, possess sharp edges, vary in colour, and in the proportions of the different minerals present in the rock. In thickness, the layers range from a few millimeters to a foot or more and are

traceable along their dip and strike for several feet. Rossman (1959, p. 4), described layers (bands) in the peridotite rocks of the Philippines, which ranged from a few grains to ten feet or more in thickness. The thickest layers on Mount Silam were noted in large boulders in stream 10 (273.60 N; 467.65 E), and measured three feet across. Such layers in the harzburgites are much less persistent than those which are characteristic of stratiform complexes (Leech, 1953; Smith 1958) and may attenuate rapidly in all directions. Complications arise in the mapping of these layers in the harzburgite rocks of the Diwata River, and in streams 9, 10 and 11 at their headwaters, where the plane of layering is parallel to the plane of foliation. Diagram 1, shows the relationship of the structures.

The direction of layering as seen in the massive harzburgite rocks of the Mount Silam strike persistently to the northeast and dip vertically, or steeply to the northwest. Layering is first seen in stream 9 (274.15 N; 467.75 E) the strike of which is N40-50E, parallel to the foliation directions; in thickness, separate layers range from 2 inches to one foot. The layers contain varying proportions of olivine in the harzburgite. In stream 10 (273.80 N; 467.65 E), thin 6 inch layers were seen where the foliation is less conspicuous in the harzburgite; the layers show a general strike direction of N40-50E, parallel to the foliation. Layering was also noted in the Kamut River (273.75 N; 466.80 E), on the Silam Mountain. Here the layers are differentially weathered; those in which there is a higher percentage of olivine in the harzburgite are less resistant to stream erosion.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO.

Plate 2. Prominent layering as seen in the peridotite rocks of the River Diwata. The plane of layering in this outcrop parallels the planes of foliation.

The layers range in thickness from an inch to 1 foot 6 inches and strike parallel to the foliation structure. In the River Diwata, the prominent foliation in part masks the layering, but in the good stream sections at Mile 6, along the river, excellent examples can be seen (Plate 1). The layers are formed by variations in the amount of olivine present in the harzburgite. At approximately Mile 6½, one exposure shows single crystals of pyroxene ½ inch in length, lying across the general direction of foliation and layering, at various angles. In stream 9 (274.05 N; 468.10 E) and stream 10 (273.60 N; 467.65 E), the layers which can be seen in large boulders, are intersected by the prominent foliation along their dips (See diagram 1).

Layering also occurs in the dunite serpentinite rocks of the Saddle Islands. Detailed mapping on the islands on a scale of 1:500 has shown that the layered structures are confined to the massive unsheared serpentinite. The planar structure is revealed by alternating layers of high and low grade chrome ore in the dunite serpentinite rock (Plate 3; see also Diagram 2), and is similar to the layered structures described by Thayer (1960, p. 207); Kovenko (1945b); Zengrin, (1947); and Couchet (1948, p. 104 - Mine Anna Madelaine Fig. 1). In the Silam area the layers range in thickness from a few grains of chrome ore to a maximum of five feet. The 'rhythmic' pattern of layering described by Wager and Deer (1939, p. 36) for the Skaargaards intrusion, is best seen in Kalung Island-Zone IV (Fig. 11), and on Rian Island (Plate 6A and 6B). The mineral changes between the layers are generally sharp in the Kalung Island layers, though gradations between the layers may be seen in the Rian Island deposit (Plate 6A and 6B). There is no evidence to suggest that the layers were formed by gravity separation such as is described by Peoples (1933, p. 357) for layering in the Stillwater Complex. It seems more probable that, since the layers in the massive unsheared rock in both the harzburgite and dunite are vertical or steeply dipping, they are due to flow layering of an inhomogeneous material partially differentiated at depth (Guild, Balsley, 1942, p. 178).

Some of the irregularities seen in the layers can be ascribed to movements in the intrusive mass when the rocks were still in a mobile, highly viscous condition. In the harzburgite of the Kamut River (274.25 N; 467.18 E), layers of olivine rich harzburgite are folded symmetrically. Erosion has truncated the folds which plunge steeply to the north, or are vertical. On the east coast of Kalung Island, layered chromite in dunite serpentinite is folded symmetrically (Frontpiece, Plate 4 and 5) in drag folds. It is evident that flowage of chrome ore took place from the limbs of the folds to the crests and troughs during these movements.

(b) Foliation. Foliation has been observed in the harzburgite rocks of the Silam Mountain. The structure is due to the parallel arrangement of the enstatite and clinopyroxene crystals which have a platy habit. Foliation is not everywhere developed and in parts of the massive rock may be absent, particularly in rocks at the eastern end of the range about the River Hitam and River Silam area, where few reliable strike directions can be obtained in the harzburgite. Towards the shear zones and zones of intense serpentinization the foliation is destroyed.

The feature is formed by the preferred orientation of the tabular faces of the pyroxene crystals along closely spaced planes in the rock. It is comparable to the orientation of mica in gneiss. In strongly foliated harzburgite the pyroxene minerals form thin lenses (Thayer, 1960, p. 207). In the Silam-Beeston area the pyroxene minerals rarely increase in length and contiguity to such an extent that they merge to form layers greater than the width of more than a few crystals. Individual pyroxene crystals are rarely more than 5 millimeters long and occur singly or scattered through the rock, or in groups forming small lenticles one or two inches long. The lenticles and scattered crystals have a definite direction which is often made more conspicuous by differential weathering of the rock surfaces. The dip component is formed by the arrangement of the crystals or lenticles along closely spaced planes which, generally, are parallel to the planes of layering (See diagram 1). The foliation structure in the massive harzburgite forms the most important structural element of the massive harzburgite rocks on the Mount Silam.

Foliation in the harzburgite rocks was first seen on the eastern side of Mount Silam above 2000 feet. In the stream 9 (274.20 N; 467.75 E), the foliation occurs in massive reddish-brown harzburgite, strikes to the northeast, and dips 65-86 degrees northwest. In stream 10, the foliated peridotite occurs in a lenticular mass surrounded by pale green serpentinite; the strike of the foliation in the harzburgite, at approximately the 1700 foot contour level, is N55-83E, with a dip to the northwest 65-87 degrees (273.82 N; 467.68 E). In the same stream section, at 2000 feet, the reddish brown harzburgite predominates and the foliation strikes consistently to the northeast, and dips to the northwest steeply. In stream 11 (273.42 N; 467.30 E), above a belt of massive pale green serpentinite, the strike is almost east-west with a dip to the north 80 degrees, but this direction quickly reverts upstream to the general direction of N50E above 2000 feet, (273.50 N; 467.10 E), with a dip of 60-80 degrees to the northwest. The general northeast direction is maintained toward the west along the Mount Silam flanks, although a subordinate east-west direction was observed in the River Puteh (273.05 N; 466.20 E). A similar variation in strike direction was observed in the small left bank tributary of the River Diwata at Mile 6. Along the northern side of the range the foliation structure is best seen in the River Kamut (273.80 N; 466.75 E), where the strike is consistantly to the northeast. Along the excellent sections of the River Diwata, the strike is to the northeast though the dip is variable, generally between 50-85 degrees. Beyond Mile 6, the strike becomes erratic and only occasionally can the north-easterly strike be determined in the slickensided rock. Towards the headwaters of the River Diwata the foliation becomes less conspicuous or is absent in the schistose serpentinite.

In general, the structure of the peridotite mass as shown by the dip and strike of the foliation and layering, is that of a sheet-like mass that strikes northeast and dips to the northwest 60-85 degrees.

(c) Lineation. This structure is thought to have developed independently of the layering and foliation during the period of intense serpentinization of the harzburgite rocks. Lineation is the arrangement of the components in the rock, in lines rather than along planes (Thayer, 1960). The massive serpentinite on Mount Silam possesses this fine lineation, which has been superimposed upon the original harzburgite structure.

The structure is formed by the parallel alignment of small rod-like lenticles of chlorite and admixed magnetite, which tend to stand out vividly in the pale rock. Individual lenticles are wavy and rarely more than 5 millimeters in length and 0.5 to 2 millimeters in thickness. The lenticles rarely occur closely spaced; but they are conspicuous enough and occur in sufficient numbers to impart a strong direction to the rock. The axis of the lineation is always horizontal.

The structure is best developed in the massive well jointed serpentinite on the flanks of the Mount Silam, away from the schistose serpentinite. Where the rock becomes less serpentinized toward the centre of the mountain the structure disappears. In stream 9 (274.07 N; 467.96 E), approximately $\frac{1}{4}$ mile to the north of the contact, the lineation is developed in massive serpentinite and trends N55E; between the heights of 1300 feet and 1500 feet (273.70 N; 467.65 E), the lineation strikes N67E; a similar direction was observed at approximately 1400 feet in stream 11 (273.50 N; 467.15 E). In the River Kamut, at 1300 feet, pale grey green serpentinite shows the lineation striking N75-80E, (274.06 N; 466.50 E). Thin bands of pale green serpentinite were also observed in the River Puteh (272.90 N; 466.06 E) striking northeast. Toward Mount Beeston, the pale serpentinite is generally sheared and the structure was not observed.

The gabbroic rocks on the northern side of Mount Silam also display a marked lineation structure. This structure is formed by rod-like lenticles of feldspar and hornblende, arranged parallel in the rock;

the axis of the lineation is again horizontal. The lineation structure is best seen in cross sections of the rock and are analogous to bundles of fibres arranged in a parallel manner. In the gabbroic dykes of the River Hitam (275.06 N; 468.45 E), the lineation trends N50E parallel to the walls of the dyke. In stream 13 (275.50 N; 468.00 E), the lineation in some of the dykes also trends parallel to the elongation of the ultrabasic mass, that is, in a north-easterly direction. In the River Kamut (275.06 N; 466.35 E), the trend is also to the north east. In the massive gabbro rock at the headwaters of the Diwata River the trend is in general N50E and east-west, though locally many variations occur.

(2) The Secondary or Tectonic Structures. The secondary structures, seen in the peridotite-gabbro complex of the Silam-Beeston range, developed subsequently to the initial period of intrusion. A series of "tectonic slices" of some larger peridotite mass at depth appear to have been upthrust toward the south along north dipping faults in the Darvel Bay area. The emplacement of the solid mass of rock probably took place, during the Miocene orogeny, as a result of intense regional compressive stress, exerted upon the mass at right angles to its general elongation. The upward movement was probably not completed until Late Miocene times.

Adjustment in the mass to the pressures was principally by shearing along the thrust planes, by block faulting, and by the bending locally of layered structures. As a result, approximately 30% of the Silam-Beeston ultrabasic mass, including the Saddle Islands, has been modified by the deformation. The dunite rocks of the Saddle Islands were especially affected and the greater part of its original layered structure has been modified or destroyed.

In the field, the thrust zones are indicated by zones of intense shearing, pulverization, or brecciation of the ultrabasic rocks. Breccias characteristically occur close to the thrust planes and typically consist of rounded or sub-rounded fragments of harzburgite and serpentinite enveloped in schistose serpentinite. The schistose rock is very variable in strike but a general direction can be seen. This variation is partly due to the fact that the planes of schistosity swing round the massive peridotite xenoliths. The fragments are thought to have been derived from the adjacent massive peridotite rock and transported several hundred feet along the thrust planes. The boulders gradually break down into schistose rock. The boulders are often slickensided, and it can be seen that the foliation structure may lie at any angle.

Breccia and schistose zones are often dyke like in character and may show an abrupt or gradual transition to massive peridotite. In the River Puteh, a breccia zone 25 feet thick passes into schistose rock, through platy serpentinite, to massive serpentinite. In general, the zone of shearing and brecciation may be only a few feet thick or, as seen in stream sections along the South Silam Thrust, they may be as much as two hundred feet thick.

(a) Thrust Faults. Though directions in the sheared rock are locally variable, the general directions along zones serve to indicate, in the field, the position of large thrust faults or slip planes. The rocks closest to the thrust planes are schistose in character. The sections seen in Map 3 of the Silam-Beeston range, shows the variations which occur along the range in the thickness of the sheared rock at the faults.

The narrowest zone of sheared serpentinite is probably not more than 200-300 feet wide and occurs along the southern margins of the ultrabasic mass on Mount Silam where the outcrop attains its maximum width of over three miles. Towards the east and west of Mount Silam, where the outcrop narrows (See Map 1) sheared rock tends to predominate, suggesting that the shear planes are numerous and closely spaced. It is possible to distinguish two main thrust faults and two subsiduary faults in the peridotite mass of the range. They are:

(i) The South Silam Thrust;

(ii) The North Silam Thrust;

(iii) The Diwata Fault;

(iv) The Cross Silam Thrust (See Map 1).

(i) The South Silam Thrust. The most important thrust fault observed in the area forms the southern boundary to the peridotite mass along the range. As shown in Map 1, the fault extends from about a half mile north of Kennedy Bay (275.06 N; 471.15 E) and runs sixteen or seventeen miles westward toward Mount Beeston. Above Kennedy Bay schistose serpentinite and gabbro are involved in the thrust (275.06 N; 471.15 E); much of the contact rocks are brecciated. Further to the west the course of the thrust appears to be traced by the River Silam; in several of the south flowing tributaries outcrops of schistose serpentinite trend east-west and possibly are against spilite rocks on the southern side of the thrust. Ultrabasic rocks occur on the spur between streams 5 and 6 (274.75 N; 469.50 E) and the thrust may possibly curve around the base of the spur (274.80 N; 469.85 E) to streams 6 and 7. In stream 6 (274.47 N; 469.60 E), quartizites strike N60E against schistose serpentinite and massive harzburgite. In stream 7 the thrust crosses low ground at approximately 274.47 N; 469.10 E. In stream 9, mudstones and graphitic shales strike 10-65 degrees south east, and dip steeply to the south east. Close to the contact the spilite schists are streaky and dips are near vertical; across the contact breccias of serpentinite occur for approximately 150 feet along the gorge (274.06 N; 468.10 E), (See sections C-C'). In stream 10, altered spilites and shales strike N54-65E and steepen in dip toward the contact from 10 degrees. Across the contact, excellent stream sections show numerous outcrops of breccia and schistose serpentinite (273.60 N; 467.65 E). In stream 11, quartzites and ophiolite rocks show a strike of N20-30E with a near vertical dip; and across the contact 100 feet of slickensided and schistose serpentinite strike N80W on the northern side of the thrust. Similar structures are shown in the small streams at 272.97 N; 467.06 E and 272.45 N; 466.25 E. In the River Puteh, altered spilites and quartzites strike N40W and dip to the northwest 20 degrees below the thrust; occasional strikes are east-west. Across the thrust, breccias again outcrop and are followed upstream by schistose serpentinite in a well marked thrust area. In the River Diwata (See Diwata Traverse Map and Section A-A'), spilite and epidote hornfels outcrop below the thrust and strike in an east-west direction. The South Silam Thrust contact is here obscure in the low ground of the Diwata valley. In the headwaters of the Diwata River the last exposure of the thrust occurs, (see Diwata River Traverse Map). It seems likely that the thrust contact continues one or two miles to the west of this point and terminates to the southeast of Mount Beeston.

(ii) The North Silam Thrust. The most northerly thrust fault that separates country rock Chert-Spilites from the gabbroic rocks of the range has not been mapped during the present survey, since this contact area was of no significance to the Company during their period of work on the Silam-Beeston range. The name "North Silam Thrust" has been given to the thrust separating largely gabbroic rocks from the peridotite of the range. This fault is ill-defined in rolling low lying ground but is thought to trend roughly parallel to the South Silam Thrust.

The position of the thrust was first observed in a small stream, about a mile above Kennedy Bay (275.75 N; 470.80 E), on the northern flank of the ridge. Schistose serpentinite outcrops in the stream and strikes east-west; downstream, on the northern side of the thrust, 10 feet of quartzites outcrop in the stream together with spilites. Further to the west, at Mile 3, along the Silam Road, the sheared serpentinite shows a very variable strike direction against brecciated and sheared gabbro (275.75 N; 470.60 E). Along the branch road that leads to the west (275.40 N; 469.50 E), sheared and brecciated gabbro outcrop in the road cutting; schistose serpentinite rocks occur on the flanks of the Silam Mountain, just above the road, and mark the approximate position of the thrust fault. In one of the small streams cutting the road (275.40 N; 469.10 E), ophiolites occur just below the contact at approximately the 500 foot contour, and show a general north-easterly strike. Toward the west, the thrust appears to swing outward into low lying ground and has not been observed in the alluvium and boulder beds. In the Kanut River, at approximately the 100 foot contour, a waterfall marks the position of the thrust. Here (274.84 N; 466.30 E), gabbro at the base of the waterfall strikes east-west against schistose serpentinite and dips to the north-west sixty degrees. The thrust zone is also seen in the River Diwata at Mile 7½, where schistose serpentinite interfingers with gabbro dykes (see Diwata Traverse Map). The southern branch of the Diwata River crosses the thrust fault zone at Mile 10½, where serpentinites, striking east-west, are against gabbro on the northern side of the thrust.

(iii) The Diwata Fault. This fault is approximately 2½ miles long and trends northeast across the peridotite mass of the Silam Beeston range (see Map 1). It is marked out by the straight course of the River Diwata tributary, which joins the main stream at Mile 7½ (see Section A-A'). Outcrops of schistose and brecciated serpentinite are common along the course of the tributary, striking N50E. Close to its junction with the mainstream, the sheared and schistose serpentinite contains angular boulders of gabbro, which are thought to have been brought up along the thrust plane from depth.

(iv) The Cross Silam Fault. This fault is approximately one and a half miles long and trends north-south across the range. The thrust fault separates the peridotite of the range from the gabbroic rocks at the eastern end of the range. This fault also involves a lense-like outcrop of spilite and cherts. The strike of the schistose rocks, as seen in stream 2 (275.00 N; 471.06 E), follows the direction of the fault, that is, north-south. The ophiolites pass into brecciated outcrops of serpentinite (275.35 N; 471.15 E) and into slickensided serpentinite striking north-south at the waterfall, toward the headwaters of the stream. The fault is marked out on the ridge above the headwaters of the stream by the depression or 'saddle' (275.50 N; 471.15 E).

<u>(b) Tensional Faults</u>. Tensional faulting is known to have affected Mount Silam. They can be recognized on the flanks where narrow ledges, two to three hundred feet wide and several hundred yards long, are bordered on one side by a steep rise of one or two hundred feet. These faults trend N50E along the mountain and are thought to be representative of the period of tension faulting which affected the whole of North Borneo, probably during the Quarternary period.

At the eastern end of the Mountain (275.15 N; 468.75 E), the stepped feature of the flanks commences at 1000 feet above the headwaters of the River Hitam and tributaries. The strike here is to the northeast; displacements can only be approximately determined by a calculation of the height of the steep side, which here is 100 feet. In streams 9, 10 and 11, the stepped feature is pronounced, though the ledges are narrow and difficult to reach. The strike is again to the northeast and the steep sides are marked by high 200 feet waterfalls in massive harzburgite; little or no brecciation has occurred, though locally narrow zones of slickensided harzburgite may be seen. In the headwaters of the River Kamut (274.15 N; 467.15 E), the stepped structure is well marked on the northern flanks. The trend is again to the northeast and the throws are approximately 2-300 feet marked by the high waterfalls.

Across the River Diwata the stepped feature is obscure in the lower ground of mainly schistose rock.

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Plate 3. Layering, in chromite deposits, is a planar feature, and is revealed by alternating layers of high and low grade ore. Kalung-Kalung Island, Darvel Bay, North Borneo.

Plate 4. Subparallel layers of dense and disseminated chrome ore, thrown into drag folds, in serpentinized dunite, East coast Kalung-Kalung Island, Darvel Bay, N. Borneo.

Plate 5. Folded subparallel layers of chrome ore. Note thickening at crests. East coast Kalung-Kalung Is., Darvel Bay, North Borneo.

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Plate 6A. Lense of Tabular Disseminated layered ore in sheared dunite serpentinite, Rian Island, Darvel Bay, North Borneo.

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Plate 6B. Close up view of the Tabular chromite ore body, Rian Island, Darvel Bay, showing the rhythmic pattern of the layering in serpentinite derived from dunite.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-
BEESTON RANGE, DARVEL BAY, N. BORNEO.

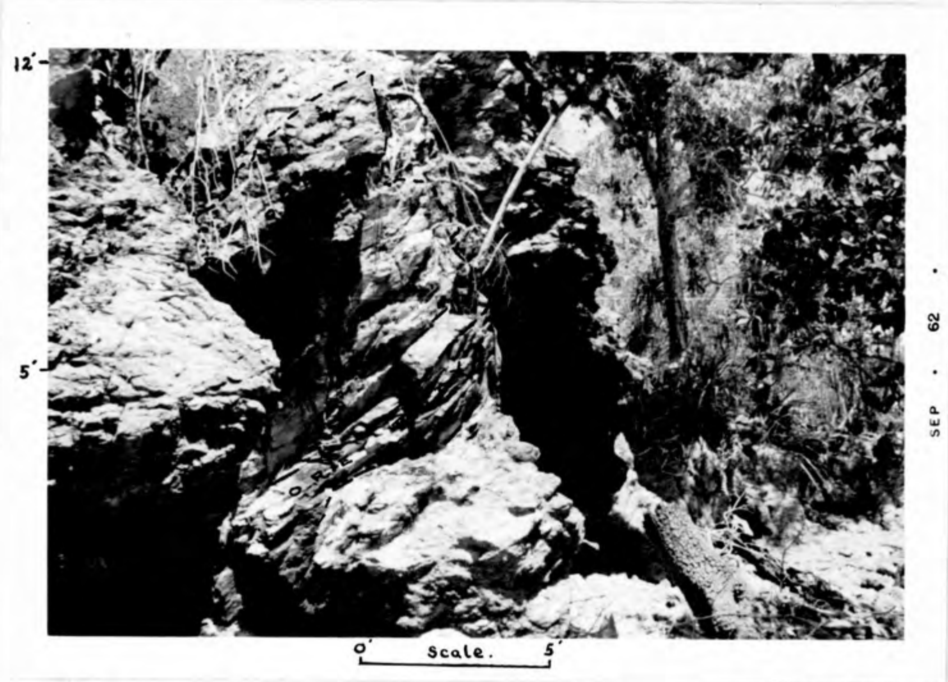

Plate 7. Layered chrome ore in serpentinized dunite swinging round from a general strike of N50W on the island, to an east-west direction. Rian Island, Darvel Bay, North Borneo.

CHAPTER V

CHROMITE DEPOSITS

General Statement

In contrast to the stratiform deposits exemplified in the Bushveld, the ores in Alpine Ultrabasic rocks are characterized by their erratic distribution, irregular form, and by their varied relations to the enclosing rocks (Thayer, 1950). Thayer has suggested the term "podiform" to cover these irregular deposits in Alpine peridotite-gabbro associations (1962, p. 204) and the term should include the sack form and fissure form deposits of Sampson (1942), and the schlieren banded or scattered type deposits.

In the Silam-Beeston area two main types of deposits have been distinguished according to the classification given by Thayer under this general term (1962, p. 204). They are:

(1) The discontinuous tabular deposit, which is the most common type of deposit in the area, and which in part grades into the Disseminated Type deposit of Thayer.

(2) The irregular deposits, which form an insignificant part of the deposits in the area.

A description of each follows:

(1) Discontinuous Tabular Deposits. Thayer (1960, p. 205), defines this type of deposit as flat lenses strung out like lima beans in a pod along dunitic zones. The bodies pinch and swell, and may consist of massive or disseminated ore, or a mixture of the two and are connected by thin strings or layers of ore. These deposits grade into the disseminated tabular deposits of Thayer (1960, p. 205).

Many examples of these tabular deposits are known in the Saddle Islands outcropping in the dunite serpentinite rocks. The localities where the deposit is well developed are described below:

Hitam Prospect - Chromite float is scattered over a wide area in the River Hitam and its smaller tributary, the Rian, at the headwaters of the River Sapagaya (275.25 N; 468.75 E). This led to the suggestion that an ore body existed at shallow depth beneath the laterite cover in the vicinity. Chromite float in the River Hitam is first seen at about the 50 foot contour level close to the confluence of the Hitam with the River Sapagaya. Upstream, the pebbles become progressively more angular and most have an average size of about 2-4" square, though occasional boulders 1 foot square may be seen. The chromite debris continues beyond the waterfall and narrow gorge, at the 250 foot contour, to the 950 feet contour and may also be found scattered on the interfluve between the Hitam and the Rian tributary. The Rian stream, which joins the Hitam at the gorge (250 foot contour), contains no chromite debris along its scoured, steep, course between the heights of 500 feet and 1000 feet. The actual ore body was found beneath 3-12 feet of laterite clay, at the top of the rise, at the 1000 foot contour; approximately 200 tons of ore was exposed. The known length of the ore body is approximately 43 feet and has a width of 23 feet. In general, the ore body strikes N40W and dips irregularly to the northeast, ten or twenty degrees. The footwall of the deposit rests on weathered schistose serpentinite believed to be derived from dunite; the hanging wall rests largely in clay and has clearly been eroded. Though the present maximum thickness is nearly two feet, the original ore body may have had a slightly greater thickness. The shape

ULTRABASICS OF THE SILAM-BEESTON RANGE.

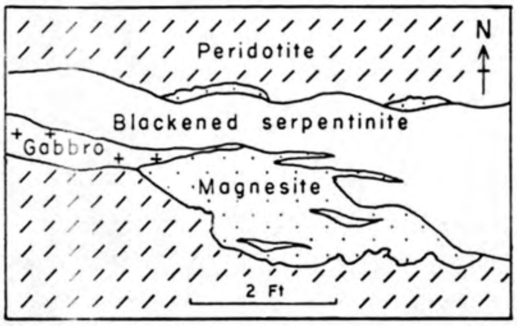

Figure 3. Peridotite blackened by gabbro and invaded by magnesite, Baik Islands.

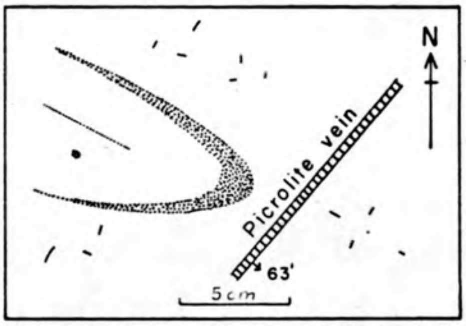

Figure 4. Fold in disseminated chromite band. Laila Islands, Darvel Bay.

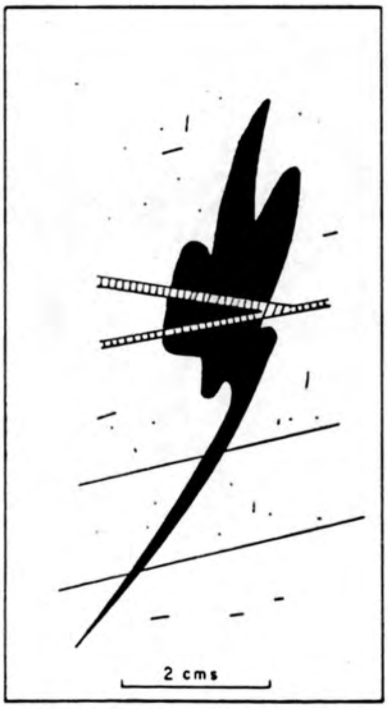

Figure 5. Inclusion of chrome ore in dunite, Kalung Islands. Contacts are sharp. Note streaks and tails of ore.

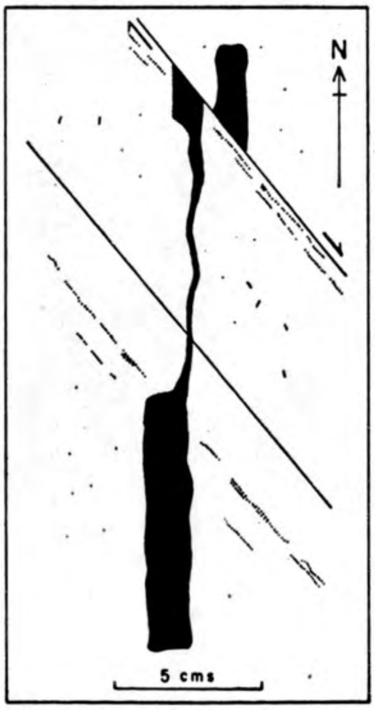

Figure 6. Inclusion of chrome ore in dunite, Laila Islands. Ore stringer has been pulled apart across local primary banding.

of the ore body is irregular, but in general, plate or tabular-shaped and shows the characteristic pinch and swell structures along its length. Though the country rock to the ore body is peridotite, as seen in the Rian and Hitam streams, the pod appears to be surrounded by a thin shell of highly weathered dunite serpentinite, 1 inch to 1 foot in thickness. The sheared nature of the dunite serpentinite and the slickensided character of the chromite, suggests that the ore body moved upward in peridotite as a solid mass and that the dunite enclosing the ore has been sliced out during the movements in a manner suggested by Thayer for a deposit in Pakistan (Thayer 1960, p. 219), where a chromite body occurs surrounded by sedimentary rocks!

Kalung Island. In the massive dunite serpentinite of the Island the layers of chrome ore stand out vividly in the coast sections. The ore occurs in zones but the zones are not continuous. The maximum known length of any one zone is approximately 50 feet. The chrome ore layers are persistent for only a few feet in the zones and frequently show small displacements along their lengths. Shearing and close spaced faults in the island appear to have disrupted the original layered structures locally. Four separate ore zones have been distinguished. They are:

ORE ZONE I - A narrow zone of banded chromite outcrops on the path at the northern end of the island. The ore zone may be traced uphill for 20 feet on a strike of N70-80W; the layers appear to terminate abruptly at the 25 foot contour level. The maximum width of the ore

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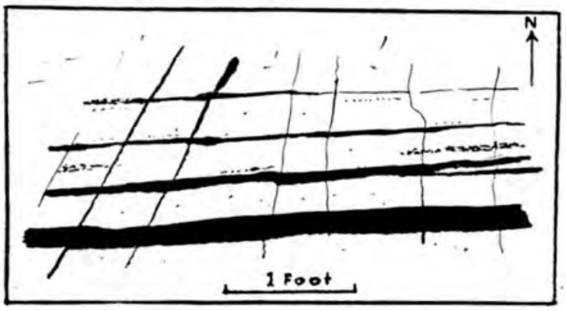


Figure 7. Undisturbed planar banded ore, Kalung Is. Darvel Bay.

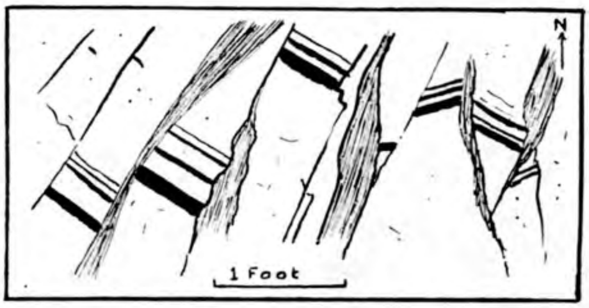


Figure 8. Planar banded ore disturbed by minor faults and shears, Laila Is. Darvel Bay.

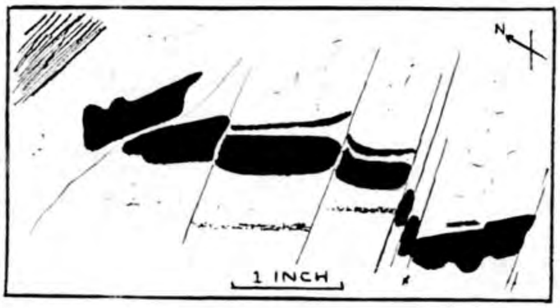


Figure 9. The break up of Tabular deposits as seen on Mainland Is. Darvel Bay.

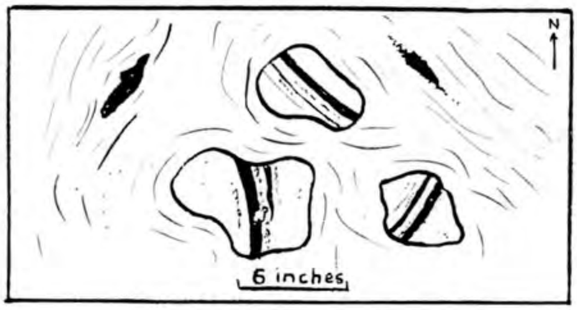


Figure 10. In many localities of the Saddle Is. fragmentation, rounding and transportation of dunite boulders in shear zones has taken place. Note the erratic strike of ore bands in sheared rock, Mainland Is. Darvel Bay.

zone is 15 feet and contains disseminations of chromite in layers $\frac{1}{4}$" to 1" thick and a more massive ore layer of 2"-3" thick.

ORE ZONE II - This ore zone occurs 150 feet from the northern headland in the east facing cliff. Thin disseminated chromite layers $\frac{1}{2}$" to 5" occur in a zone 75 feet in length, directed N20-70W. Blocks of massive dunite, at the cliff base, contain $\frac{1}{2}$" to 5" thick layers of chromite folded into symmetrical anticlines and synclines (Plate 4 and 5). The layers thicken at the crests from 1", on the limbs to 8" at the crests. This ore zone appears to be faulted and may possibly be the continuation of Ore Zone 1.

ORE ZONE III - In a zone of total width 60 feet, 12 layers of chrome ore occur in the cliff face, striking N75W and dipping 80-85 degrees to the north. The layers in the cliff face commence at 10 feet above sea level, as thin disseminations and thicken gradually to $\frac{1}{2}$" and 1" layers at the base of the cliff. Along the same strike at low water level, a layer of disseminated chromite 1 foot thick occurs, 25 feet from the cliff. Many large boulders were found at the base of this cliff containing $\frac{1}{2}$" to 7" thick layers of ore.

The strike of this ore zone suggests that it is the southward continuation of ore zones I and II. The layers also suggest a gradual thickening with depth down to sea level.

ORE ZONE IV (fig. 11).- This ore zone contains the thickest chrome ore layers exposed in the Saddle Islands in massive, well jointed serpentinized dunite, along the southwestern headland. The zone has been traced for 150 feet in the intertidal regions and consists of numerous discontinuous layers of chromite, 1/8" thick to 2 feet thick, striking N50-75E and dipping vertically or steeply to the north 60-80 degrees. The layers pinch and swell rapidly and attain a maximum thickness, near Peg 74, of five feet and a length of 14 feet (Peg.83, Fig. 11). A N20W fault cuts out this ore body at its northeastern end. The strike of Ore Zone IV suggests that it is a separate ore zone from those described above. The chromite layers possess a well defined lineation structure, the direction of which is parallel to the walls of the layer; the axis of the lineation is horizontal (Diagram 2).

As seen in the cliff face the separate layers again suggest thickening with depth (Section A'-A Fig. 11). From ¼" layers, 12 feet above sea level, the layers expand to 1-5 feet thick ore bodies at the low water mark.

Laila Island. Similar layered ore occurrences to those of the Kalung Island Ore Zone IV, may be seen on the southwestern headland of Laila Island. The layers occur in a zone 200 feet wide and 100 feet long between high and low water marks. The zone has a similar strike to that of Ore Zone IV, Kalung Island, that is N50-60E dipping steeply to the south 50-80 degrees; the layers range in thickness from 1/8" to 1/2" with local thickenings of up to 2 feet. The ore has the same mottled leopard skin appearance as ores of the Kalung Island (LI. 39), and also possesses a similar lineation structure. Figure 8, is a sketch of layers on the Island which have been displaced by minor faulting.

Island 5. In the south facing cliff of the island, 400 feet from the southwest headland, an ore body 2" to 3" thick has been traced for

5 feet along a strike of N65W. The layers are $\frac{1}{2}$" to 2" thick in an ore zone 1'6" wide. The ore is fine grained and finely jointed. The ore body appears to be cut out by sheared serpentinite, invaded with silica, at the northern end.

<u>Saddle Island 7</u>. Chromite occurs in the south facing cliff of the peninsula, some 300 feet northeast of the southern most tip of the island. The chromite appears as layers in sheared serpentinite, 12 feet above the shore line, at Peg. 12. The ore body has the shape of an inverted letter L and appears to follow the direction of shearing, N50W. The ore body is 1 foot thick at the base and thickens upwards over a distance of ten feet to 3'3". The ore body is fractured and slickensided, in part granulated and contains variable quantities of interstitial silicate material.

The ore body suggests that it has been torn off from an original layer of chromite, during a period when the dunites were extensively sheared.

<u>Mainland Island</u>. A 2-3 feet thick layer of massive fine grained chromite is believed to have given rise to the many slickensided ore boulders, on the western side of the island, along the northwest headland. The boulders measure from 2 inches to 1 foot across. Pits and trenches have been dug at this locality in the sheared serpentinized dunite and revealed several more fragments and boulders measuring 1 foot across embedded in the weathered material. The evidence suggests that the original layers have been destroyed by closely spaced fractures and that the boulders have been scattered along the shear zone. A similar occurrence of such scattered

ore in highly sheared material has been found on Malawali Island, near Kudat.

Rian Island. The deposit exposed in the cliff face of the island falls into the Disseminated Tabular Type Deposits of Thayer (1960, p. 205) which he defined as disseminated ore (Schlieren plates in European terminology) in which layering, parallel to the long dimensions, is characteristic and in which the contacts along the edges of the ore layers are sharp or ill defined. The ore body of Rian Island appears to form a part of an original zone of layered ore that has been segmented and strung out into shear blocks by post magmatic faulting (Thayer 1960, p. 205). The fragments of the ore zone can be traced for 150 feet on the island along a general strike of N50W. In the cliff face of the island, the ore body strikes N50W and dips to the south 30 degrees. The ore body has a thickness of 2 feet 7 inches and a total length of ten feet and consists of many alternating layers of high and low grade ore, separated by variable thicknesses of white-yellow weathered serpentinite, derived from dunite. Individual layers or bands range from 1/8 inch to 7 inches thick; along the strike the layers divide, coalesce and attenuate irregularly (Plate 68, & 16, 18, 19). The northern end of the ore body bends upward sharply terminating in frayed ends and the boundaries of the ore body irregularly cross the internal structure of the ore body (Plate 6a).

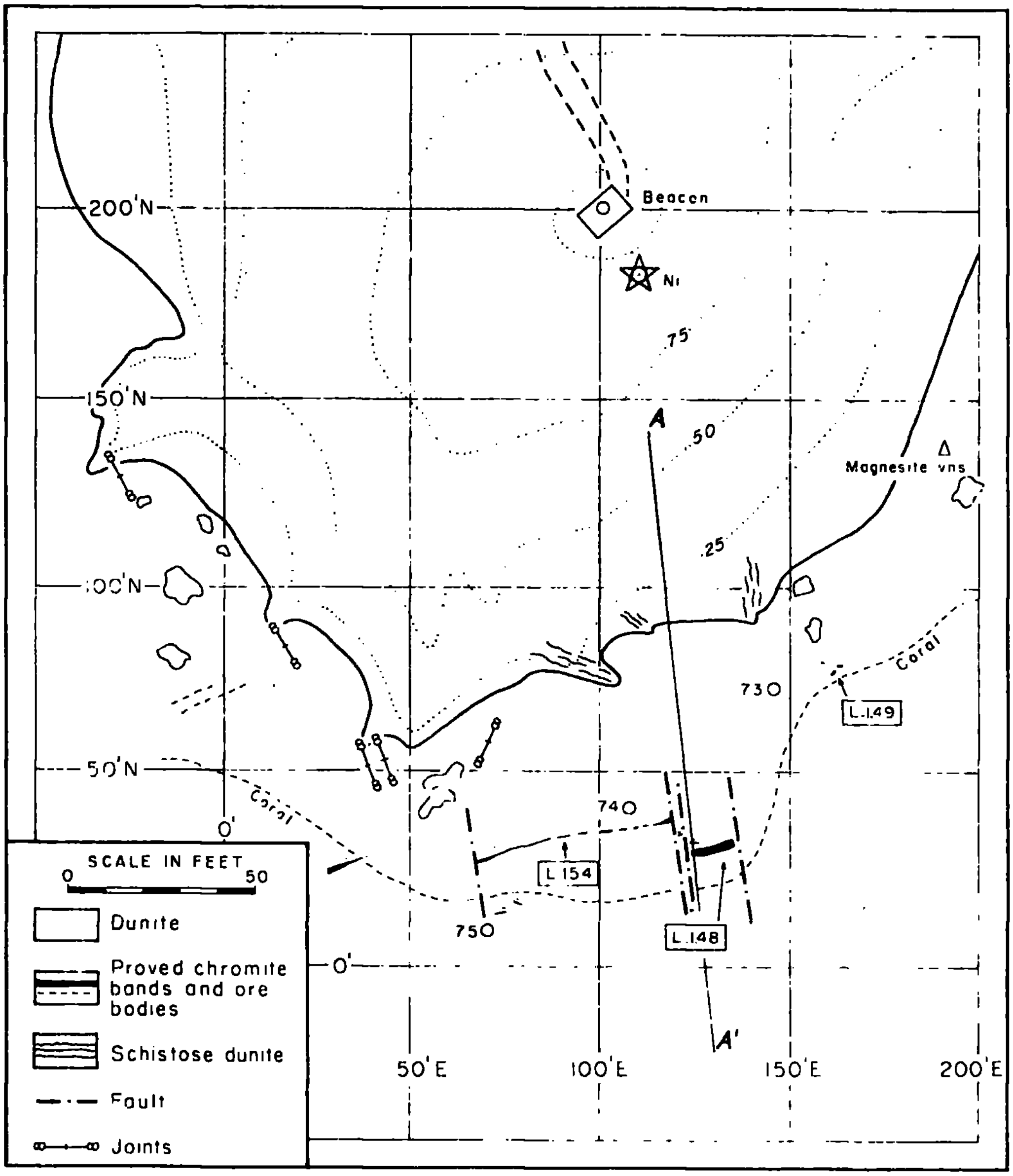
Towards the northern end of the island, twenty five feet from the last ore body, similar disseminated ore is also exposed in the cliff face. From the general strike direction of N50W, the attitude of the ore body abruptly changes to an east-west strike and appears to have been rotated about a near vertical axis (Plate 7).

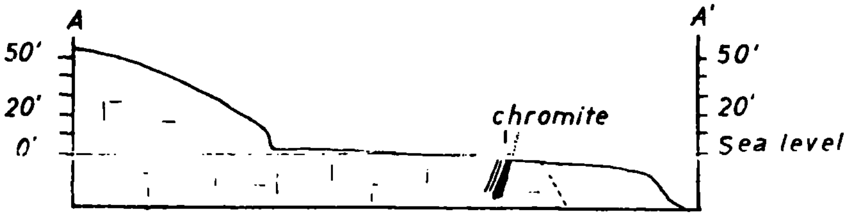
2. <u>Irregular Deposits</u>. The irregular deposits (Thayer 1960, p. 205) may be large or small and are characterized by their extremely irregular form. Many examples have ameoboid extensions or protuberences and defy simple description. Most of the examples of this type of deposit in the Saddle Islands are generally small.

In Fig. 5 and 6, typical examples of this type of deposit are shown. The blebs are always of massive ore with little or no visible gangue material. Thayer (1960), suggests that the gangue has been squeezed out during their formation. They typically possess sharp outlines against the enclosing dunite, suggesting that the viscous blebs of chromite, separated from larger ore layers, were intruded into unconsolidated dunite. A similar structure was seen in the Katai ore deposit, in the Labuk Valley, in which the separated blebs of ore in the massive dunite appeared to have been rolled. Fig. 6 shows how blebs of ore can be pulled apart along their length. On Rian Island a stringer of ore blebs dip steeply in the dunite and possess rounded edges.

<u>Petrography of the ore</u>. In hand specimen, the chrome ore is brownish-black in colour with a dull metallic lustre, or blue-black with a sub-metallic lustre (L.S. 49). The average crystal size ranges between 2-3 millimeters, though in some of the chromite boulders, found in the River Hitam, crystals measured 5-6 millimeters across (L.S. 51). Octohedra were not found. Though much of

FIGURE 11 GEOLOGICAL MAP OF A CHROMITE OCCURRENCE IN THE KALUNG - KALUNG ISLANDS (ZONE IV, S.W. POINT)





Section along line A-A'

the ore seen on the Saddle Islands is massive in character, specimens collected from the Mainland Island (L.I. 82) and the Hitam Prospect, on Mount Silam, show conspicuous evidence of cataclastic deformation. At both localities the ore is heavily slickensided and in part tectonically polished on the joint surfaces; in L.S. 51, from the Hitam ore body, individual crystals have been flattened and have wavy surfaces.

The gangue in the massive chromite frequently imparts a lineation to the ore. This structure is best seen in the layered ores of the Kalung and Laila Islands. Here the gangue forms narrow 1-2 millimeter lenticles in the ore, the long axes of which are aligned parallel and, generally, horizontal. On Laila Island the direction of the lineation roughly parallels the N42-50E strike of the layers (Peg. 29). On Kalung Island (Peg. 84; L.I. 47), however, the lineation generally parallels the strike of the layers, that is N80E, but slight discordances may be seen locally, when the direction of the lineation trends across the strike of the ore body. In the Hitam ore deposit the lineation is poorly developed over much of the ore body; around Peg 8 a poorly defined lineation direction was taken to be N40E.

In thin section the chromite grains are anhedral, ragged in appearance and show mutual embayments with the gangue and opposing crystals (LM. 2). Thin filaments of the gangue, between the crystals, may be the only means of determining the grain size in specimens of massive ore from Kalung and the Mainland Island. Serpentine minerals form the bulk of the gangue material in the ores; dewylite ($4H_9O.3SiO_2.6H_2O$) was recognized by X-ray determination (L.S. 50), (Information supplied by Naylor, Benzon & Co., Ltd.).

Mineralogy of the Chromite. Chromite is the only ore of chromium. The ore has a specific gravity of 4.1 to 4.9. The brown streak and low magnetic susceptibility distinguishes the mineral from magnetite, which is found as a frequent accessory mineral in the dunites of the Saddle Islands.

Chromite is a member of the spinel group of minerals and like most of them is an isomorphous mixture (Stevens 1944, Vol. 29, p. 24) of several and members or minerals. In its purest form it is a chromate of iron, and is expressed by the formula $FeCr_2O_4$, giving the percentage of Cr_2O_3 as 67.9. The mineral is never found in such purety, since chromium can be isomorphously replaced by aluminium and ferric iron, and the ferrous iron by magnesium so that the commercial ore is a mixture of these elements, and rarely contains more than 50-55% chromic oxide.

The value of the chromite ore depends not only upon the chromium content, but upon the iron content as well and these two elements are expressed as a chromium to iron ratio , which is the quotient of the percentage of chromium, divided by the percentage of iron. For industrial purposes metallurgical ore is used for the manufacture of ferro-chrome steels and requires a chromium content of 48% and a chrome to iron ratio of 3:1. In refractory grade ore, the content of aluminum is of importance; the sum of the chromic oxide and aluminum oxide should exceed 50% (Wells, F.G. and Smith, p. 40, 1945).

Seven complete analyses have been made of the chrome ores of the Silam Beeston area, the results of which are listed in the accompanying table from information supplied by Messrs. Naylor, Benzon & Co., Ltd. The samples of chrome ore have beem taken from the Hitam Prospect, on Mount Silam, and from several localities in the Saddle Islands. The chromic oxide content of the ores taken from the islands show a high average percentage of Cr_2O_3, that is 48.74%. The iron content ranges between 9.31% to 12.61% and, since the microscopic evidence shows little or no alteration of the chromite grains, the iron content shown in the tables probably represents the original percentage in the mineral. Cr:Fe ratios are thus high in the ores taken from the Saddle Islands, about 3:1; L.D. 4, has a ratio of 4:1, thus these ores can be described as being of metallurgical grade ore. They are similar to the Turkish ores, but the overall analyses are too high in silica for good quality basic brick making. The ore is also too fine grained and would shatter on firing.

The ores taken from the Hitam prospect show a marked difference in composition to those of the Saddle Islands. The average chromic oxide content is much lower, being 32.72%. The substitution of ferric oxide for chromic oxide in the Hitam ore body, probably accounts for the higher Fe_2O_3 content, which averages 13.77% average. Thus the Hit^am ore has a lower chromium to iron ratio and can be classed as a refractory grade ore.

TABLE 1. CHEMICAL ANALYSES OF CHROMITE FROM THE SILAM AREA

	SADDLE ISLANDS				HITAM PROSPECT		
	1 Average of 1A,B,C	1A Fine-grained chromite in boulder, Mainland I. (L.M.2)	1B Chromite in banded ore, Kalung I. (L.I.4)	1C Chromite in crushed ore, Ore-zone II, Island 6 (L.I.6)	2 Average of 2A,B	2A Coarse-grained chromite in boulder (L.S.49)	2B Coarse-grained chromite in boulder (L.S.50)
Cr_2O_3	48·74	50·48	47·37	48·48	32·72	32·90	32·55
Al_2O_3	10·06	10·47	9·25	10·48	25·15	24·05	26·25
FeO	11·11	12·61	9·31	11·41			
Fe_2O_3	2·34	0·22	5·06	1·76	13·77	13·80*	13·75*
MgO	18·77	18·76	18·40	19·15	18·92	18·80	19·05
CaO	0·66	0·95	0·61	0·44	0·12	0·35	NIL
SiO_2	6·57	4·77	8·61	6·33	6·75	7·85	5·65
Na_2O	0·07	0·08	0·09	0·04			
K_2O	0·04	0·04	0·05	0·04			
Loss on ignition	1·99	1·75	2·07	2·15	2·80	3·00	2·60
	100·35	100·13	100·82	100·28	100·23	100·75	99·85

Analyses supplied by Naylor Benzon Company Limited.

*Total iron as Fe_2O_3

MAGNESITE

	BAIK ISLAND
	1 South headland; L.D. 15 Massive amorphous magnesite
SiO_2	-
Al_2O_3	0.10
Fe_2O_3	0.08
FeO	-
CaO	0.65
MgO	47.40
Na_2O	-
K_2O	-
Cr_2O_3	0.10
Loss on ignition	51.30
Total	100.00

Analysis supplied by Naylor, Benzon & Co. Ltd.

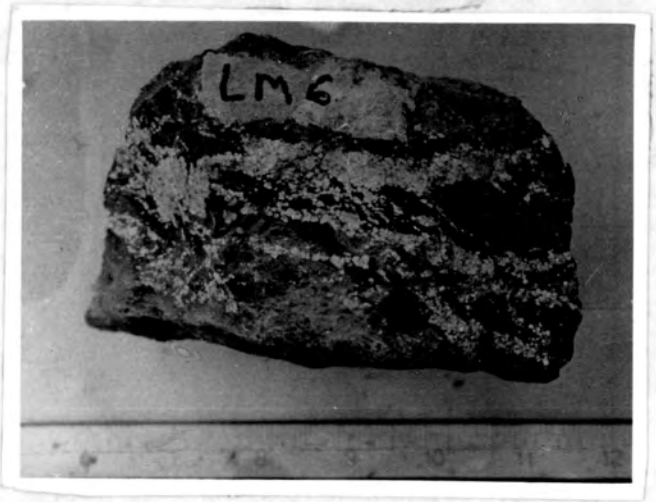
Magnesite occurs as disseminations, streaks, veins, and pods in the sheared serpentinites in many parts of the Saddle Islands. The ore was not encountered on the Mount Silam and only one occurrence is known at the headwaters of the River Diwata. The ore is cryptocrystalline, massive, white to grey in colour and possesses a marked conchoidal fracture. Weathering of the ore produces bulbous growths on the surfaces. Notable occurrences may be seen on Baik Island, Saddle Island, Kalung

Island (plate 8), Island 6 (Plate 9), and the Mainland Island. The specimens collected all have variable amounts of admixed silica, though some, as on Baik Island,possess a high proportion of MgO. The magnesite is thought to have been derived from the breakdown of the serpentine minerals during periods of metamorphism and it a noteworthy fact that the greatest amount of magnesite ore is to be found in close juxtaposition to the dykes of pyroxenite that cut the serpentinite rocks of the Saddle Islands.

Plate 8. Veins of magnesite in dunite serpentinite, Kalung-Kalung Island, Darvel Bay, North Borneo.

Plate 9. Schistose serpentinite impregnated with magnesite ore (white), and intruded by layered gabbro (centre) and pyroxenite (foreground), Island 6, Saddle Islands, Darvel Bay, North Borneo.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, N. BORNEO.



Plage 10. Dunite serpentinite impregnated with magnesite, Mainland Island, Darvel Bay, North Borneo.

Plate 11. Dunite serpentinite veined with opaline silica Laila Island, Darvel Bay, North Borneo.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-

BEESTON RANGE, DARVEY BAY, N. BORNEO.

Plate 12. Prominent foliation in Harzburgite, from the headwaters of the River Kamut, Mount Silam.

Plate 13. Breccia of serpentinite (dark fragments) and sandstone, veined with calcite (white), from the headwaters of the River Bole, N.E., of Mount Beeston.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-

BEESTON RANGE, DARVEY BAY, N. BORNEO.

Plate 14. Vein of gabbro cutting serpentinized dunite, showing the thermal metamorphic effect (dark colour) in the serpentinite.

Plate 15. Alternating layers of serpentinized dunite (dark), and pyroxenite (light), at the margins of the pyroxenite dyke, Giffard Island, Darvel Bay, North Borneo.

Plate 16. Subparallel layers of disseminated chromite in dunite serpentinite, with a divergent layer, Laila Island, Darvel Bay, North Borneo.

Plate 17. (L.I. 48). The distribution of the silicate gangue in high grade chrome ore imparts a lineation structure to the ore body on Kalung Island (Zone IV), the axis of which is generally horizontal.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, N. BORNEO.

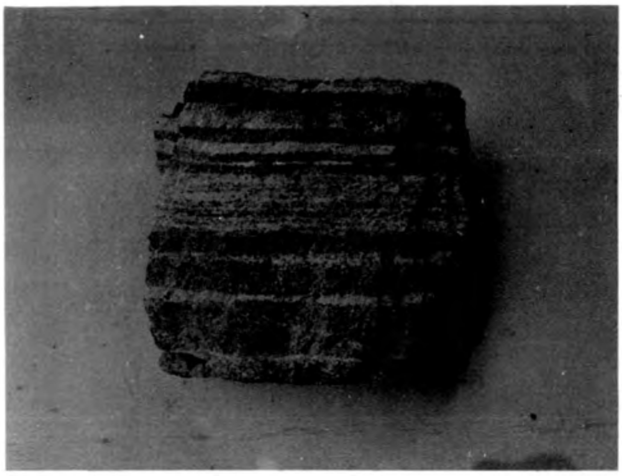


Plate 18. (L.I. 24). Tabular disseminated chromite from Rian Island, Darvel Bay, showing the rhythmic pattern of chromite layering (dark), in serpentinite (light).

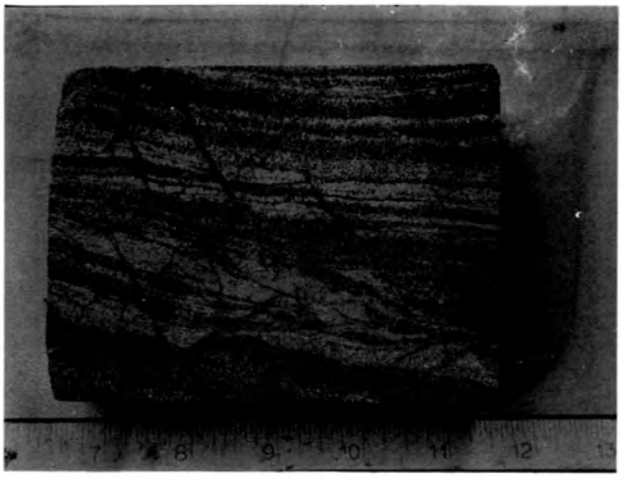


Plate 19. (L.I. 37). Tabular disseminated chromite from Saddle Island, Darvel Bay, showing the rhythmic pattern of the chrome ore (dark) layering in serpentinite (light).

CHAPTER VI

GENESIS OF THE ULTRABASIC ROCKS

General Statement

From the field evidence as outlined in the previous section, there can be little doubt that the sequence of events in the Silam-Beeston area follows the same general pattern as that which Turner and Verhoogan (1951, p. 201) suggested for the igneous and tectonic histories of Alpine areas. The deposition of siliceous cherts and great thicknesses of lava, of predominantly basalt and spilite composition, was widespread throughout the geosynclinal belt that stretched from the Philippines through North Borneo to the Celebes.

According to Bowen (1951, p. 247), "gravitational settling of olivine separating from a basaltic magma, is a well established mechanism capable of producing magmas of this (peridotite) type". Turner and Verhoogan point out (1951, p. 247) that, if alpine peridotites represent a crystalline fraction differentiated from basaltic magma, they should be "expected to be accompanied by other and more siliceous rocks representing the complimentary differentiate". It seems unlikely that the small occurrences of siliceous rocks - granodiorite and granite - mentioned by Fitch (1955, p. 67) in the Segama and Darvel Bay Area, represent these differentiates from such large amounts of lava. It seems more likely that the ultrabasic rocks of the area represent mobile masses of crystalline material that have been separated from a peridotite substratum and squeezed upward as intrusive bodies, as suggested by Turner and Verhoogan (1951, p. 244); de Roever (1957); and G.v.d. Kaaden (1860, p. 119); and others.

Two separate phases have been recognized in the history of the ultrabasic rocks of the Silam-Beeston range. They are:

(1) The Initial Magmatic Intrusive Phase; and

(2) The Post Magmatic Phase of Emplacement and Deformation.

<u>(1) The Initial Magmatic Phase</u>: The initial upward movement of the ultrabasics probably took place during the late Eocene period and during the closing of the geosyncline. The peridotite must have been in a highly viscous condition but mobile. Lateral compression forced the ultrabasic rocks to break away from a substratum and to ascend (Turner and Verhoogan, 1951, p. 224) into the Chert-Spilite Formation. The Saddle Islands ultrabasic rocks represent a separate intrusive mass into the formation. The primary igneous structures are believed to have developed during this initial phase.

The layering and foliation in the Alpine type peridotite-gabbro complexes are mose closely related, genetically, to structures developed by flowage of the rocks (Balk, 1937) than to layering derived from crystal settling such as seen in the stratiform ultrabasic complexes (Thayer, 1960, p. 207). The dunitic material and chromite grains were probably concentrated into irregular masses before the ultrabasic rocks were intruded and their present tabular form was maybe attributed to flowage of the magma (Guild, Balsey, 1942, p. 180); and Stoll (1948, p. 445) under intense lateral stress. The small drag folds, which occur in dunite serpentinites of Kalung Island and in the harzburgite at the headwaters of the River Kamut are thought to have been formed during this early intrusive period (Plate 4 and 5). Locally, the foliation cuts across the harzburgite layeres structures. It thus appears that the foliation developed independently (Thayer, 1960) and was superimposed upon the layered structures.

(2) The Post Magmatic Emplacement Deformation: The present day position of the ultrabasic mass in the Silam-Beeston range, cannot be attributed merely to igneous intrusion. There is abundant evidence to suggest that, subsequent to the magmatic phase, the ultrabasic rocks were further squeezed upward by intense lateral compression. The ability for large masses of ultrabasic rock to move into higher crustal levels in the "solid state" has been recognized by many authors: Thayer (1942, p. 247); De Roever, G.v.d. Kaaden, (1960, p. 119); K. C. Dunham (1949?); Turner and Verhoogan (1951, O. 242), and the phenomena appears to be typical of alpine intrusions. The crystalline masses of peridotite ascend along weak planes or major dislocations (Benson, 1926, p. 75-76; Hess, 1948, p. 432-433), probably concordantly in the geosynclinal sediments.

The tabular or lense like mass of the ultrabasic mass of the Silam-Beeston area, moved southward along steeply dipping thrust planes that strike, in general, to the northeast. The thrust planes dip steeply to the north west 60-80 degrees. The gabbroic rocks on the northern side of the range moved upward contemporaneously with the ultrabasic rocks, the two rocks being separated by a similar thrust plane. Pyroxenite and gabbro rocks intruded the ultrabasic rocks pre-serpentinization times.

Serpentinization occurred when the mass reached the temperature stability range of serpentinite and occurred in the presence of abundant water. Bowen and Tuttle (1949), suggest that a slowly advancing crystalline mass of peridotite absorbs water, especially at the periphery, from the invaded wet sediments to provide the fluids for serpentinization of the harzburgites. It has been shown in the Silam-Beeston range that serpentinization is most intense along and adjacent to the North and South Silam thrusts. Serpentinization decreases away from the thrust planes toward the centre of the massive rock in Mount Silam and away from the smaller internal surfaces of rupture and differential slip. It seems likely, that the fluids derived from the wet cherts and spilites of the country rock were controlled, during their ascent by the channels along the thrust planes. The serpentinites thus formed, then became loci for further extensive shearing and served as an effective lubricant for the upward migrating 'solid rock'. The massive blocks of harzburgite, seen at the centre of the intrusion, on Mount Silam, are envisaged as having moved upward at a quicker rate than the schistose serpentinites at the contacts, which must have suffered 'drag' effects. The process is likened to clay being squeezed through any available crack in a fairly ridged block, by lateral pressure. Locally, as seen on Rian and Baik Island, fragments of country rock chert-spilite were incorporated into the serpentinite schists and carried upward as xenoliths in the manner suggested by Turner and Verhoogan (1951, p. 242).

The intense lateral compression upon the ultrabasic rocks greatly modified the internal structure of the least resistant rock - dunite-in the area. The erratic strike and the haphazzard distribution of the layered ore, on the Saddle Islands, is only explicable by such large scale "flowage" of the rocks in the solid state. The tabular shaped ore has been strung out into blocks, along the shear zones in a manner suggested by Thayer (1960, p. 205), during a period of intense compression. The separated slabs of ore are often bounded by slickensided fault surfaces, such as occur on the Hitam deposit. Thus, in many deposits of this kind, it is only possible to recover scattered blocks or fragments, usually of high grade ore, in serpentinized schists, as for instance on Mainland Island (No. 9). Stoll (1958, p. 444), considers that slabs of ore may assume a mechanically more stable form in the shear zones and are capable of being carried upward as solid enclosures. Thayer suggested for the Cuban ores (1942, p. 26-27) that they were formed at a much greater depth and were carried upward as solids in the peridotite rocks to their present positions.

A similar mechanism is thought to have been operative in the Silam area and appears to have occurred at several localities in North Borneo. In the Malawali Island for instance, slabs and fragments of ore occur scattered in pulverized serpentinite on Pranggi headland. On Banggi Island, at the Kapitangan Prospect, blocks of chrome ore lie in the stream and may possibly have been eroded out of the schistose serpentinite as a slab of chromite from the hill side and fragmented in its present surface position by stream action. Thus if the chromite deposits, as seen in the Saddle Islands are regarded as xenoliths, then the relation between the erratic strike of the separate blocks or layered zones in the dunite serpentinites and the country rock are seen to be consistant (Thayer, 1960, p. 207). The understanding of this relationship is fundamental: attempts to anticipate an ore body, beyond half its known length, only tends to baffle the prospector.

The alignment of the Silam-Beeston range, parallel to the east-west structures in the Miocene sediments, in the Segama Valley area, suggest that the upward movements of the ultrabasic rocks took place during the Miocene period. A period of crustal shortening occurred as the peridotite-gabbro complex was pushed southwards along steeply dipping thrust planes.

Rapid arching of the Silam-Beeston range along an east-west axis, during the Miocene orogeny, with complimentary rapid sinking of the Darvel Bay area (Kirk, 1962), must have disrupted a previously established drainage system of the Diwata and Segama rivers. The River Diwata is an excellent example of antecedent drainage and is thought to have cut into and across the east-west axis during the period of uplift. River capture might also explain the sharp bend of the River Diwata, at Mile 6; this river may have joined the upper Segama tributary - the Bole - which was cut off by the rising land mass in the area. Uplift along the east-west axis of the range, would also explain the sudden diversion to the north in the course of the RiverSegama, which must have previously emptied into Darvel Bay, near Lahad Datu. This river now swings to the north for approximately twenty miles, then turns sharply to the east to its estuary, above Dent Haven (see Fig. 1).

A period of young tensional faulting has affected the intrusive rocks of the Silam-Beeston area and has resulted in the marked stepped topography of the flanks of Mount Silam. Tension faults may also have diverted stream 9, to the southwest and cut out the northward continuation of the Saddle Islands ultrabasic sheet on the mainland (see Map 1). These tensional faults may have occurred at the same time as the extensive Quaternary fissure eruption of basalt in the Mostyn area, about 20 miles to the south of the Silam area, described by Kirk (1962, p. 100).

CHAPTER VII

APPENDIX

In the Silam Beeston area, nineteen streams drain the northern and southern flanks of the mountain range and have been numbered as in Map 2 (see Pocket). Excellent geological sections occur in many of them, though above two thousand feet on the Mount Silam, access is difficult and dangerous. The most important of these stream sections are described below.

River Diwata Traverse (Map No. 1).

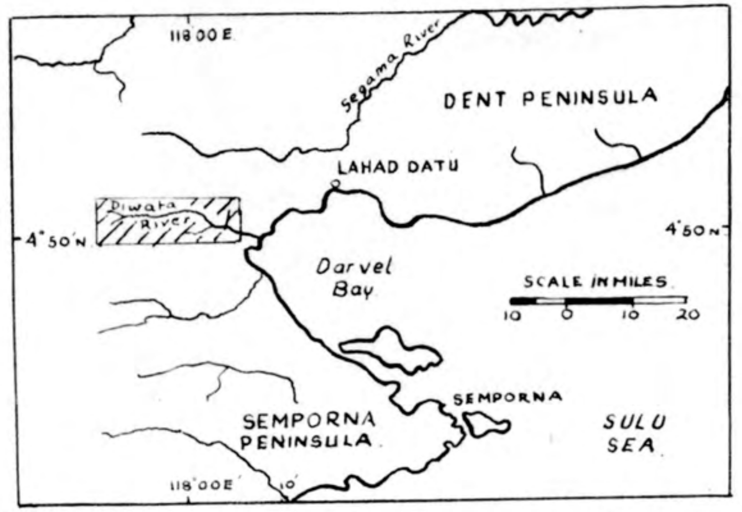
The River Diwata drains the western portion of the Silam-Beeston range and flows into Darvel Bay, approximately 20 miles from the main town of the region, Lahad Datu. The catchment area of the river, on the range, covers approximately 24 square miles and thus, is the largest river system in the area described. Shallow draught boats are capable of reaching mile 1½, just above the inland edge of the mangrove swamps, at the point where Borneo Mining Limited made its base camp. The alluvial flats continue for half a mile inland.

From the estuary the river meanders through low lying ground in rocks of the Chert-Spilite Formation, up to Mile 5.

At Mile 2, outcrops of quartz and epidote hornfels occur in the stream section and at Mile 5 streaked mudstones occur, with epidosite breccias, striking east-west.

Above Mile 5, the main river crosses over the contact in a poorly exposed section, into ultrabasic rocks. The first exposures

RIVER DIWATA TRAVERSE MAP. 1



INDEX MAP SHOWING LOCATION

KEY

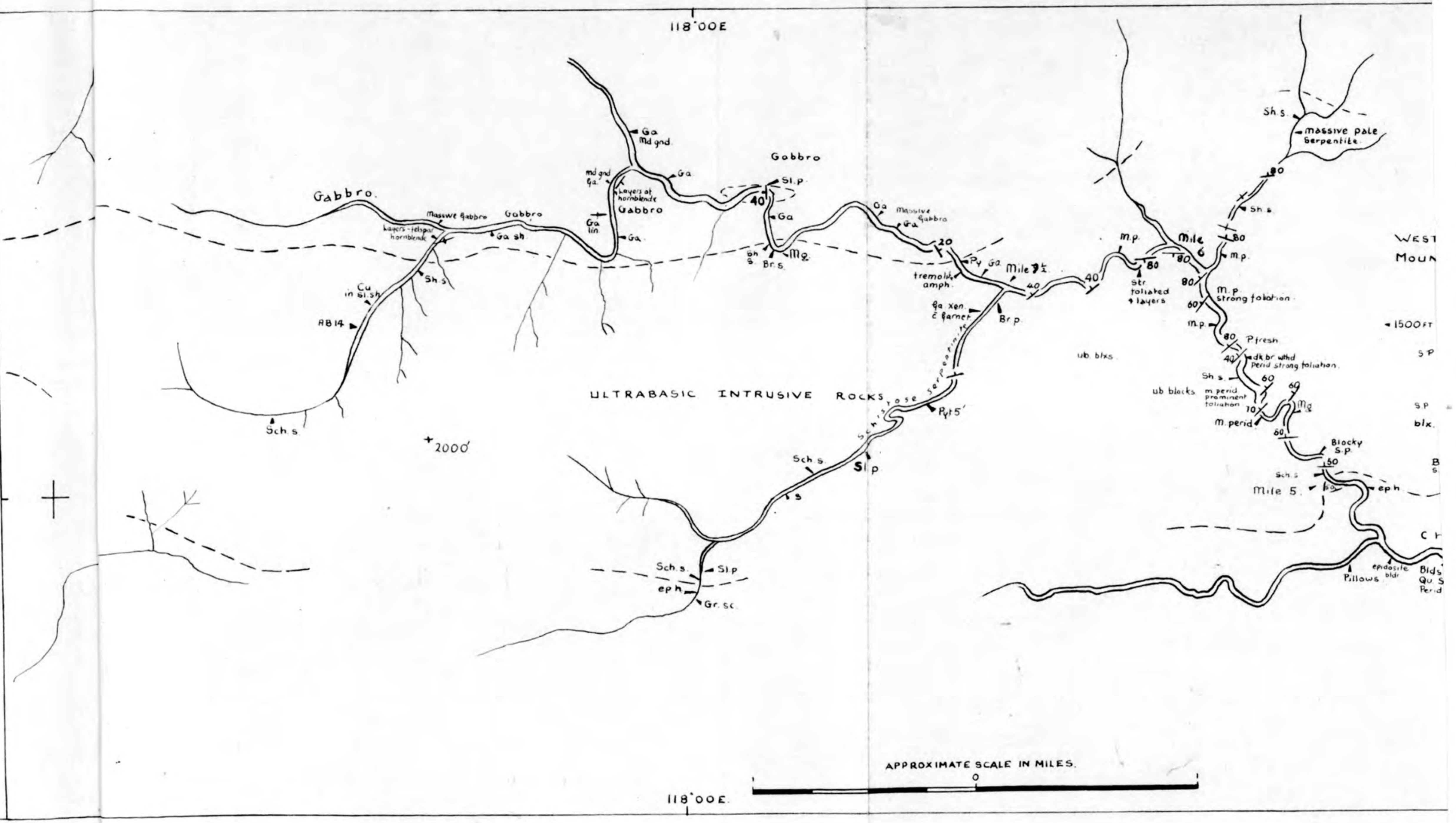
P. Peridotite.
S.P. Serpentinized p.
m.P. Massive p.
Sh.s. Sheared serpentinite.
Sch.s. Schistose serpt.
Py. Pyroxenite.
Br.p. Brecciated perid.
Sl.p. Slickensided perid.

Ga. Gabbro.
Ga.sh. Gabbro sheared.

ep.h. epidote hornfels.
Gr.Sh. Graphite schist.
Qu. Quartz.

Cu. Copper.
Mg. Magnesite.

50 Strike of foliation & layering.
Vertical dip of foliation.
Locality of observation during Survey.
LS 50. Specimen No.



consist of breccias and schistose serpentinites, the strike of which was noted as N70E dipping steeply to the north. The sheared rock continues above the contact and passes through slabby peridotite to massive serpentinized peridotite. The peridotite is pale to dark green and in parts exhibits a strong foliation, which consistently strikes to the northeast. Dunite segregations occur, occasionally as narrow 2-3 feet wide layers, concordant with the general strike and dip of the foliation. Fresh peridotite occurs in massive rock towards the centre of the ultrabasic mass, at Mile $5\frac{1}{2}$ to Mile 6, where the foliation is very conspicuous.

Toward the sharp westward bend in the river, at Mile 6, the valleys are steep sided and tributaries of the river flow into the main stream over a waterfall 100 feet high. The peridotite here shows a consistent foliation that strikes N50E and dips vertically or steeply to the northwest. Compositional layering in the rocks strikes parallel to the foliation and complicates the mapping of the separate structural features at this locality. Approximately 100 feet round the bend, at Mile 6, to the west, crystals of pyroxene were observed cutting across the layers, singly and in groups of two or three; the strike and dip of these crystals was found to be markedly different from those seen in the lenticles of pyroxene, which form the foliation. Further upstream the strike becomes more variable and close to the northern contact strikes vary between N20E and east-west and N50E with a general dip to the NW 30-50 degrees.

At Mile $7\frac{1}{2}$, the north-easterly flowing tributary, that cuts across the east-west axis of the ultrabasic mass, joins the main stream. Approximately 100 feet up this tributary, xenoliths of altered gabbro occur in an outcrop of sheared serpentinite. The boulders are 6" to 1' across and may be rounded or angular in shape. Some show a metasomatic alteration around their contact margins and Dr. Kirk (1962) found garnets and prehnite in some of the specimens. Just below Mile 1, pyroxenite occurs, in a dyke 10 feet wide, cutting slickensided and sheared serpentinite. The pyroxenite is flow layered and the strike of the layers is more or less parallel to the walls of the dyke. The course of this tributary, here, is almost straight and the abundance of schistose serpentinite and breccias suggests that it is fault guided. Sheared, black shales and epidote hornfels are against schistose serpentinites along the southern contact.

The northern branch, which is the main stream of the river, flows roughly westward from Mile $7\frac{1}{2}$. Layered pyroxenite occurs approximately $\frac{1}{4}$ mile above the confluence of the two rivers. Serpentinized and brecciated pyroxenite occurs in one outcrop. Dr. Kirk described one exposure in the stream of tremolite amphibolite overlying pyroxenite and showing a sharp contact. Just above this point, gabbro becomes an important rock member and occurs interfingering in the contact schistose serpentinites. Hornblende gabbro rocks become the dominant rock across the contact at Mile 8. Where the river swings south, in a meander at Mile $8\frac{1}{2}$, serpentinites are seen sheared against metasomatized gabbro in which Dr. Kirk found abundant prehnite. Magnesite occurs as low dipping veins at Mile $10\frac{1}{2}$. The contact is a steeply dipping zone of weathered, iron stained, crushed serpentinite and gabbro, along a thrust zone that probably runs in an east-west direction. Where the river swings to the north a narrow lenticular mass of schistose serpentinite cuts the stream, in hornblende gabbro.

At Mile $10\frac{1}{2}$, the River Diwata branches again into a northern and southern tributary. The northern tributary continues to run in massive hornblende gabbro, which, in part, is layered with segregations of hornblende and feldspar minerals; the lineation is variable, but in general it is directed east-west. The southern tributary, the course of which describes an arc and flows to the northeast, contains a good section of serpentinized, schistose and brecciated serpentinite. Approximately half a mile from the confluence, the slickensided surfaces are coated with fine flakes of pyrite. Gabbro rocks continue on the northern side of the range, toward Mount Beeston, in hilly and difficult country; the width of the ultrabasic outcrop narrows and may possibly terminate here in gabbro rocks.

River Puteh Traverse

The River Puteh is a tributary of the River Diwata, which drains the western end of the Silam Mountain (See Diwata Traverse Map). It has a catchment area of approximately 3 square miles and the main stream has a length of over three miles, commencing at 2,000 feet. The stream flows roughly southwest and joins the River Diwata, after swinging southeast, at Mile 4.

From the River Diwata, the tributary flows over rocks of the Chert-Spilite Formation. Close to the contact with ultrabasic rocks, a narrow dyke of gabbro cuts the cherts in an east-west direction. This is followed upstream by an outcrop of quartzite, striking N40W and dipping northeast 20 degrees against altered spilite rocks, streaked in an east-west direction. The contact with the main mass of peridotite is obscure, but across the contact to the north, 100 feet of breccias occur in a good stream section. This is followed upstream by intensely slickensided and schistose serpentinites in a thrust area. At the division of the stream, into eastern and western tributaries at Mile 2, folds and breccias occur in serpentinites.

The eastern branch shows schistose, brecciated, serpentinites in thrust zone for approximately $\frac{1}{4}$ mile. In part calc-silicates veins traverse the rocks. The serpentinites grade into slabby peridotites and massive rock, further upstream, away from the contact. At approximately the 200 feet contour level, the peridotite foliation is conspicuous and strikes in a north-easterly direction dipping steeply to the northwest. Joints in the massive rocks strike to the north with a subordinate direction east-west.

In the western branch of the River Puteh, more massive peridotite rock is encountered, close to the confluence of the two streams, in which the strike of the foliation continues to be N30-60E, but with a southward dip of 35-80 degrees. This is followed upstream by further outcrops of spinel blebs, in dunitic rock, striking N40E; nearby calc-silicate veins traverse the rock east to west. 200 feet upstream, the foliation is conspicuous and strikes N80W and east-west, in massive blue peridotite, containing thin bands of gabbro that follow the same general direction. This passes upstream to black peridotite, containing thin $\frac{1}{2}$ inch bands of pyroxenite (L.S. 223), weathered white. Towards the headwaters the foliation direction returns to N50E, dipping northwest in massive blue black peridotite.

Stream 9. This stream, which drains the southern flank of Mount Silam, has a length of three miles and flows from its headwaters, at 2,300 feet, taking a south-easterly course towards Darvel Bay. Approximately half a mile from the coast, the river swings round to the southeast and flows along a straight course for approximately half a mile before turning again south Darvel Bay. The river appears to flow along a fault that cuts out the northerly continuation of the Saddle Island's dunite (See Map 2, 273.25 N; 468.85 E).

Sheared serpentinized dunite outcrops in the stream, just below Mile $1\frac{1}{2}$, at the bend of the river, (273.25 N; 468.85 E). Disseminations of chromite occur in the schistose rock, which show a strike of N70W. Where the river divides into an east and west tributary, an outcrop of gabbro occurs, in spilites, and strikes N40E. Spilite, quartzite and epidote hornfels outcrop along the course of the stream up to 1,000 feet; the strikes are generally to the northeast and they show a southward dip of 35-60 degrees. Towards the contact the spilites and mudstones become progressively more schistose and streaky in character and in part are quartz veined; the dip of the shear zones is 10-35 degrees to the southeast. At the contacts the dip becomes steep and, in part, almost vertical.

On the northern side of the contact, breccias and sheared serpentinite outcrop for approximately 150 feet along the gorge and then pass quickly into massive serpentinized peridotite, which, in turns, passes into fresh peridotite. A well developed cuboidal system of jointing may be seen in the cliff face. The stream narrows rapidly and the flanks become precipitous. A high 200 feet waterfall prevented further examination of the stream beyond the contour level of approximately 1,900 feet. At this point a foliation structure was observed in massive red-brown harzburgite, the direction of which is N50E.

Stream 10. This stream drains the central portion of the southern flank of Mount Silam. It is approximately 2 miles long and flows towards Darvel Bay, taking a southeast direction. Approximately half a mile from the coast the river swings sharply to the southeast and probably marks the western continuation of the fault as seen in stream 9. Spilites and quartzitic rocks outcrop in the stream section, at approximately the 800 feet contour level, striking N30E-25E. Towards the contact, epidote hornfels and pale hydrothermally altered spilites and graphitic shale strike N54-65E and dip to the northwest 10-20 degrees, parallel to the alignment of Mount Silam. The streaky character and flow structures in the rocks, become more prevalent over the last 200 feet, below the contact. Across the contact, breccias and shear zones are conspicuous along the excellent stream sections; they strike N80E and dip to the northwest 35 degrees, in a northwest dipping sheet structure. Some pyroxenite boulders occur, but the source rock is not exposed. The peridotite upstream passes into blocky and platy serpentinite at the position of the landslide, (N273.60; 467.80 E). Joints of the peridotite are coated with calcite, zeolite and quartz and in some parts garnierite occurs as thin veneers along the joints of fresh rock specimens. A pale blue-white altered gabbroic rock, also occurs among the boulder debris. At the 1,500 feet contour level a massive rock outcrop of serpentinite occurs. This has a strong lineation caused by thin lenticles of chlorite and admixed magnetite. At the 1,500 feet to the 2,000 feet contour, foliated harzburgite occurs.

Stream 11. This stream, approximately two miles long, drains toward the southeast and south, from the western part of Mount Silam, between the River Puteh and stream 10. Buff coloured sandstones are the first rocks to outcrop along the lower course of the stream (N272.65; 467.75 E) approximately at the 100 feet contour. Spilites and quartzitic rocks, containing fine crystals of pyrite, occur as boulders in the stream, for several hundreds of feet. At the five hundred feet contour, the stream divides into an east and west branch. The main stream, on the eastern side, up to the 1,000 feet contour, continued to flow over spilites and quartzitic rocks, the strike of which is N20-30E, with a vertical dip. About 100 feet of slickensided serpentinite occurs in the stream flanks across the contact and strikes N80E to eastwest. This is followed a little way upstream first by a lense of serpentinized dunite and then by pale green serpentinite at the waterfall. A lineation is distinct in parts of the serpentinite and tufa forms bulbous masses in the cliff face, where calcareous solutions have emerged along fractures in the serpentinite. Upstream, the rocks are less serpentinized and are more massive in character and possess a well developed cuboidal jointing system in some of the rock faces. The foliation in the peridotite strikes N30E. Above this point, to the headwaters, harzburgites predominate together with the subordinate pale serpentinites.

River Silam (5). This stream is approximately 2½ miles long and runs directly east to Kennedy Bay from the eastern end of Mount Silam

(Fig. 2), just below the Kennedy Bay Timber Camp. The river maintains a fairly straight course and for the greater part flows over low lying terrain and boulder beds. About a mile from the river mouth, sheared cherts and spilites outcrop in the side of the stream and strike N70W. The southern contact of the ultrabasic rocks is thought to be only a few hundred feet away from the stream at this point, since ultrabasic rocks are known to outcrop in two of the left bank tributaries nearby (Fig. 2). Sheared peridotite and serpentinite strike N70E in the waterfalls of these tributaries. About ¼ mile upstream, in the third left bank tributary, a 10 feet thick gabbro dyke is exposed at the confluence and strikes N70W and dips to the north 60 degrees. Along this tributary, dark, blue-grey peridotite is exposed above 100 feet and is heavily slickensided.

A ¼ mile upstream from this last tributary, brecciated gabbro outcrops in the stream section and strikes N10E. This is followed by further outcrops of gabbro in schistose serpentinite striking N70E. The surrounding serpentinites pass upstream into platy and blocky slickensided peridotite, in which the amount of pyroxene increases in quantity to as much as 50-60% of the rock. Towards the headwaters, in a small gorge, the peridotite is massive in character and one specimen was found in which the pyroxene is a porphyritic (L.S. 24). Joints are consistent over short distances in the poorly developed cuboidal jointing system.

River Hitam. This stream has a length of approximately two miles and flows northwards, from 1,000 feet on the eastern end of Mount Silam, towards the River Sapagaya (Map 2). At the confluence of the Hitam River and the River Sapagaya, angular boulders of chromite are seen in the extensive boulder fan. The first outcrop consists of slickensided serpentinized peridotite, in the left bank of the stream, approximately 200 feet upstream, from the confluence. This is followed by outcrops of black, serpentinized peridotite and pale green peridotite in the cliff edge. Sheer directions are N80W and the dip is to the south, 60 degrees. This is followed upstream by extensive, wide, shear zones of slickensided peridotite, with occasional intervening blocks of massive peridotite. A lenticular mass of dunite outcrops at approximately the 200 feet contour level and is associated with a blue-black rock in which the pyroxene content is less than 5% of the rock.

Following the division of the River Hitam, at the 150 feet contour, the peridotite becomes blocky, with occasional shear zones cutting the outcrops in a general east-west direction. The internal structure of the blue-grey peridotite in both the tributaries, is obscure and few strike directions of the foliation in the rocks were found to be reliable. The stream in the eastern tributary is cut by a thin dyke of gabbro N30E, at the 200 feet contour level (Map 2).

Stream 13. This stream forms the headwaters of the River Sapagaya. From its starting point, at approximately 700 feet on Mount Silam, the stream runs north approximately parallel to the River Hitam. Gabbro dykes are numerous in the stream and cut serpentinized, slickensided, peridotite. The first dyke, at the 100 feet contour, strikes N40E; upstream, highly slickensided and schistose serpentinites are cut by streaky hornblende-gabbro, N80W and N80E. The dyke is 10 feet wide and possesses distinct chilled margins against the serpentinite contact rocks, which are stained with iron. Further upstream, other dykes of gabbro cut serpentinized blocky peridotite, in the general direction of northeast and show a dip to the south 60-80 degrees.

Kamut River (14). The River Kamut drains an area of approximately 6 square miles of Mount Silam and flows in general to the northwest. The main river in the system is thought to be the headwaters of the River Bole, which drains into the River Segama. Along the northern foothills of the range, gabbro predominates in the streams, as boulder debris and as massive outcrops. Occasionally pebbles of the Chert-Spilite Formation occur. Towards the contact upstream, the gabbroic rocks become more prevelant, mainly in dyke form, with each outcrop separated by boulder debris. The contact is exposed just below the first division of the main stream at a waterfall. Gabbro outcrops at the base of the waterfall, against schistose serpentinite and strike in an east-west direction in which occur occasional boulders of gabbro (xenoliths), and a dyke 2 feet thick striking eastwest and dipping to the south 45 degrees. Upstream, the dykes of gabbro striking eastwest become numerous, though they are generally only 2-5 feet wide and show a variable dip to the north or south in schistose or slickensided serpentinite. At 1000 feet, the lineation in massive serpentinite is conspicuous and is directed N85E; the axis of the lineation is horizontal. Between 1500 and 2000 feet the stepped topography of the ridge becomes more marked, where massive harzburgite outcrops. The foliation is well marked striking N75E to east-west with dips steep to the northwest or vertical.

The eastern tributary of the system, that joins the main stream close to the contact area, has a length of 4 miles. Boulder debris predominates in the river up to the 500 foot contour level, where outcrops occur of sheared material striking in general to the northeast.

Massive grey-green serpentinite occurs in the stream section, at approximately the 1000 foot contour and exhibits a clear lineation structure. The axis of the lineation is predominantly horizontal and the trend is, in general, N65-70E. Upstream, the topography is stepped; level areas of two to three hundred feet wide are separated by 1-200 foot waterfalls. Harzburgite was encountered in one of the falls the foliation of which is striking east-west and dipping to the south 45 degrees. One hundred feet upstream, highly weathered gabbro occurs, in a scree slope, on the flank of the stream and is presumably derived from a gabbro dyke. Above this last point, on the waterfall, the harzburgite is prominantly layered. The layers are 1 inch to 3 inches in thickness and are folded; the crests of the folds point to the north and the plunge is steep to the north; the folds have been truncated by stream erosion.

Toward the headwaters of the stream, reddish-brown massive harzburgite outcrops are continuous and show a strong foliation that, in general, strikes to the northeast.

CHAPTER VIII

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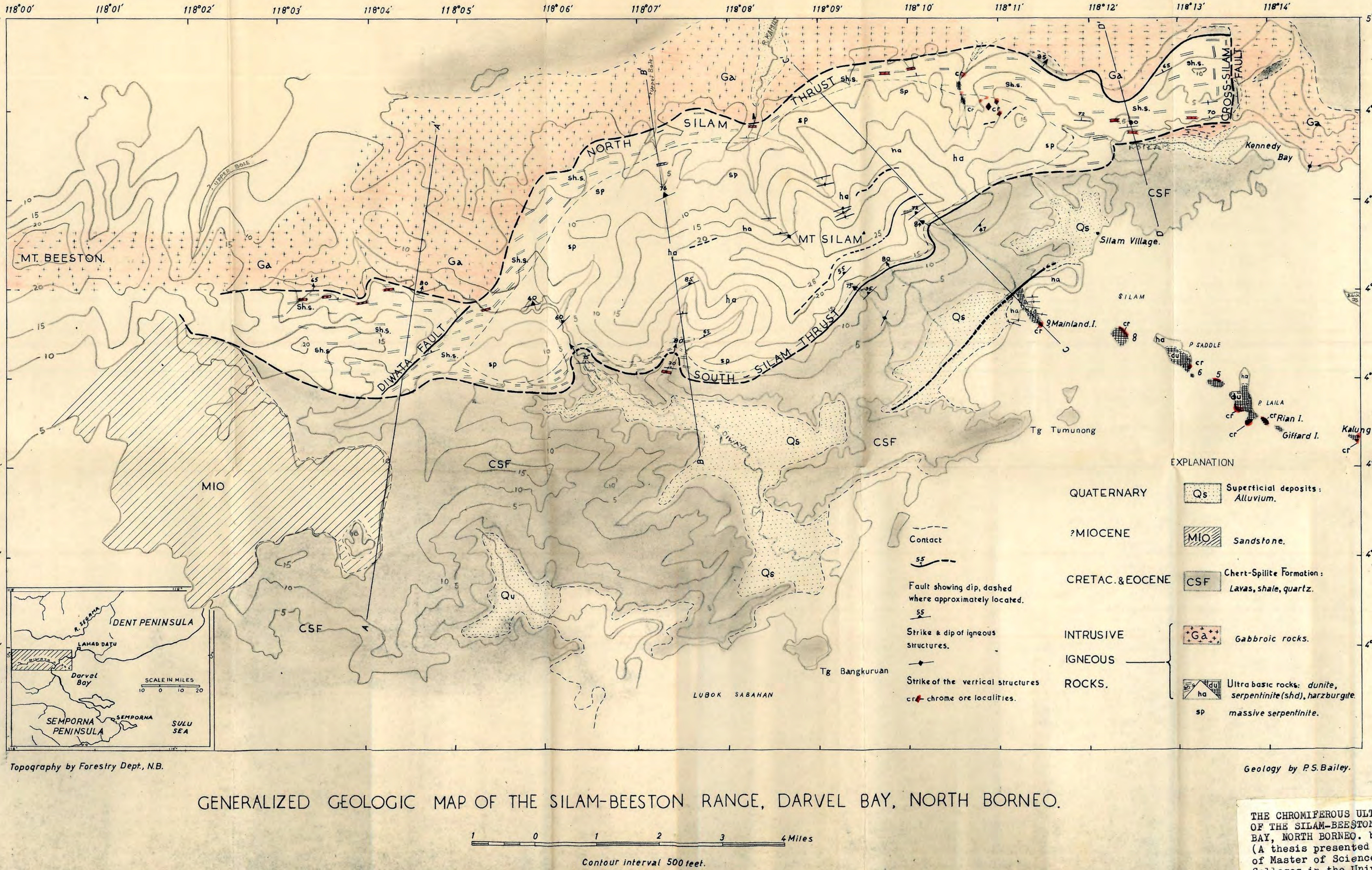
MAP 2.

TRAVERSE MAP OF THE MOUNT SILAM AREA

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO. by P.S.Bailey. (A thesis presented for the Degree of Master of Science at the Durham Colleges in the University of Durham, September 1963.

MAP 1.

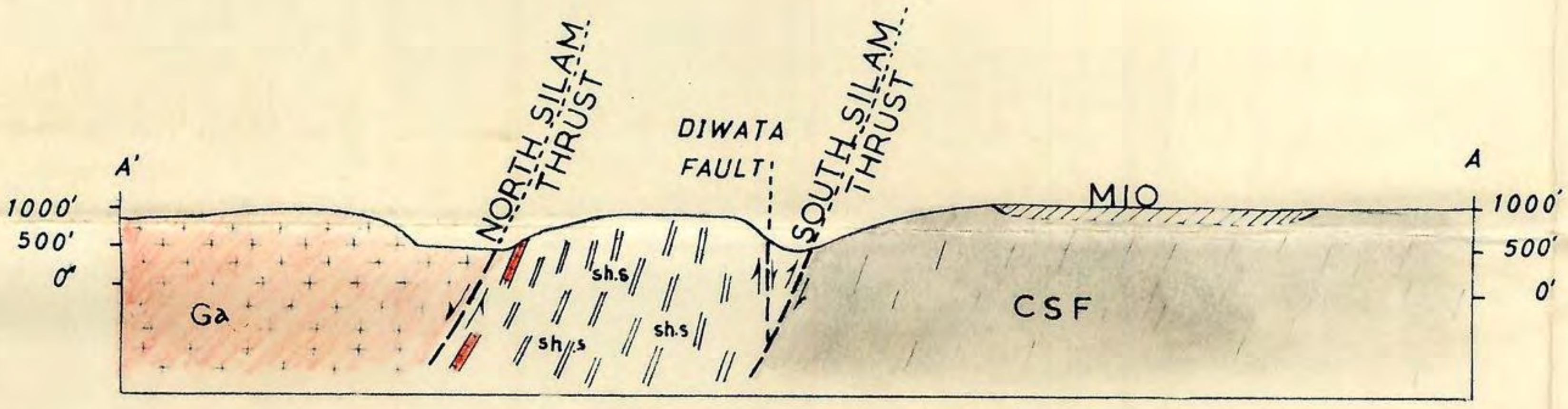


Topography by Forestry Dept., N.B.

Geology by P.S. Bailey.

GENERALIZED GEOLOGIC MAP OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO. by P.S.Bailey. (A thesis presented for the degree of Master of Science at the Durham Colleges in the University of Durham, September 1963.



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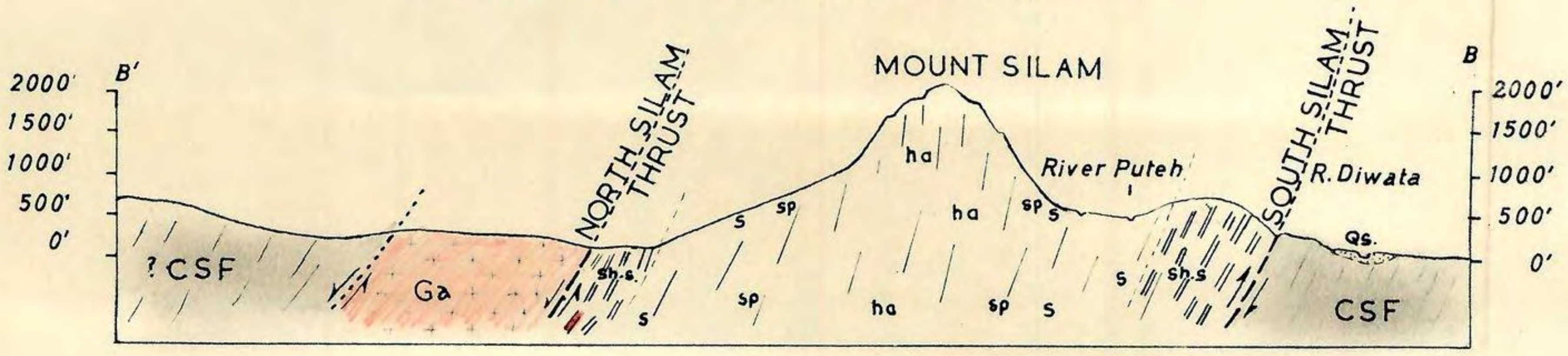

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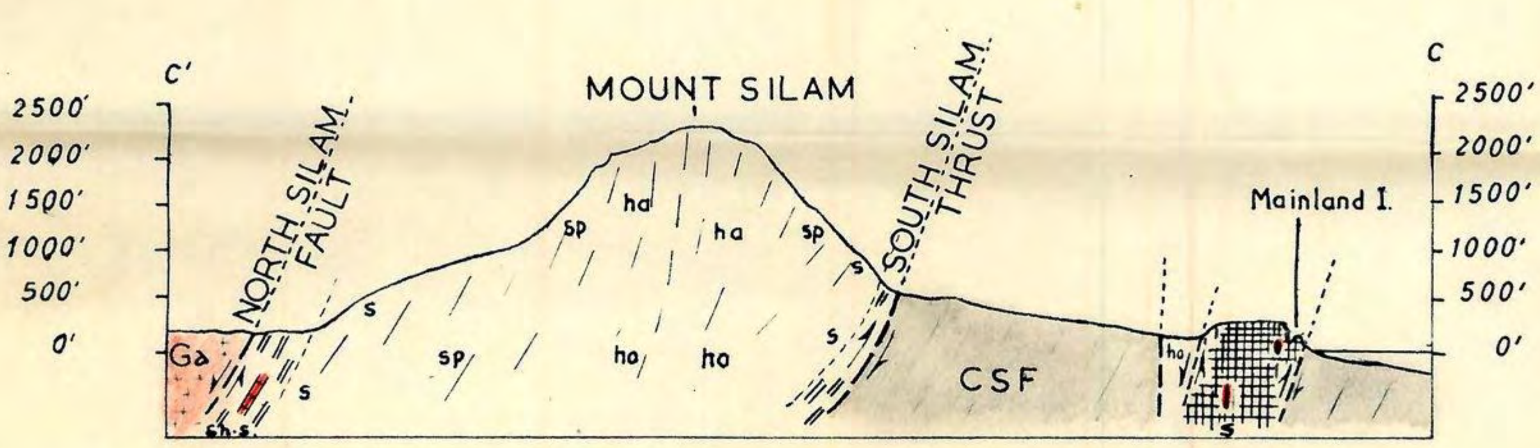

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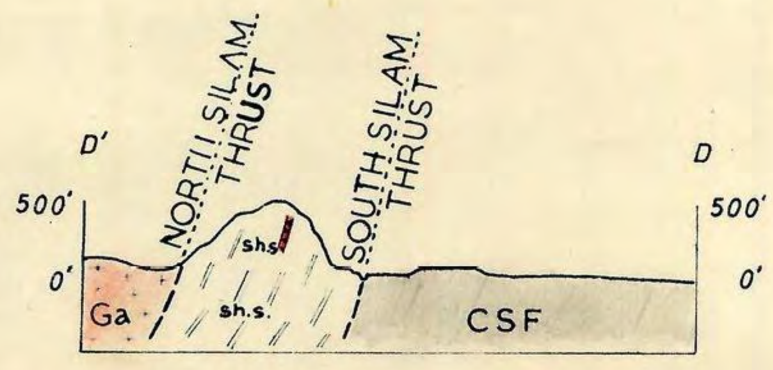

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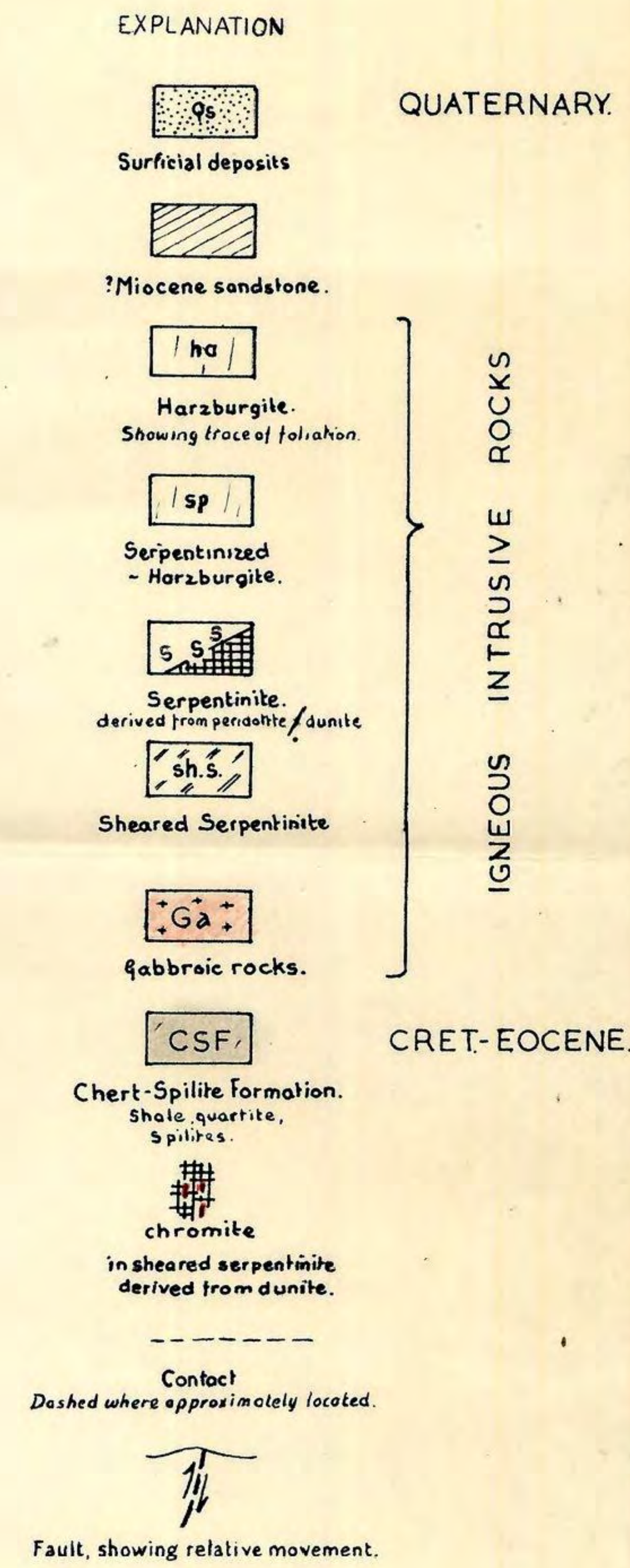

CROSS SECTIONS OF THE SILAM-BEESTON RANGE.

THE CHROMIFEROUS ULTRABASIC ROCKS OF THE SILAM-BEESTON RANGE, DARVEL BAY, NORTH BORNEO. by P.S.Bailey. (A thesis presented for the degree of Master of Science at the Durham Colleges in the University of Durham, September 1963.